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Energy Technology Screening Criteria

by
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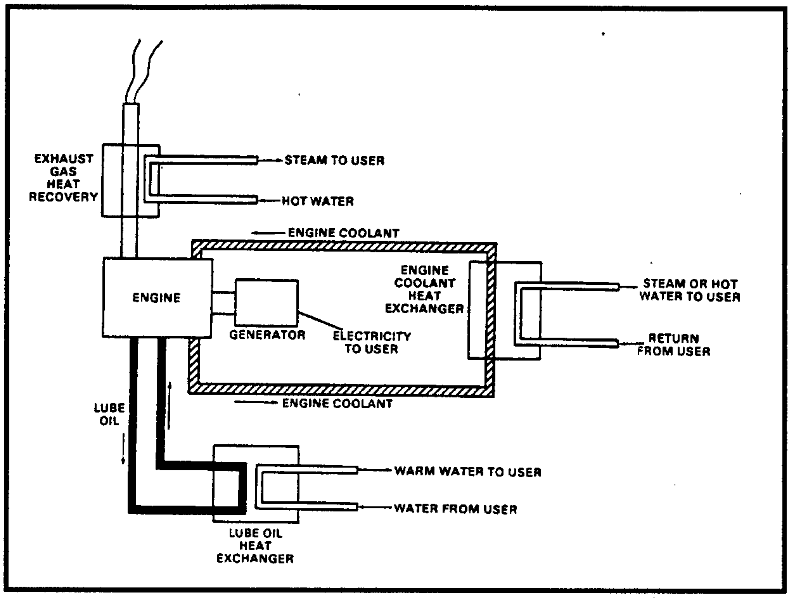

Federal energy policies promote the increased use of clean-burning natural gas for industrial and commercial process applications, and it is anticipated that the Department of Defense (DOD) installations will join in this trend over the next decade. Public and private development efforts over the past few years have resulted in gas energy conversion technologies with improved efficiencies, reduced emission levels, and lower life cycle costs. Advanced natural gas technologies such as ultra-low emission burners, gas turbines, and natural gas cooling systems are likely to play an increasingly important role at DOD facilities.

The Government already has a software tool, the Renewables and Energy Efficiency Planning (REEP) program, for evaluating alternative Energy Conservation Opportunities (ECOs) at United States military installations. However, there exists a need to incorporate new and evolving gas-fired energy conversion technologies in its database and to update evaluation algorithms as well as technical and economic performance characteristics for ECOs included in the current version of the REEP program. This report provides DOD facility engineers with a set of performance criteria for selected current and advanced natural gas technologies to be used to develop technology screening agents for the REEP program.

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Federal energy policies promote the increased use of clean-burning natural gas for industrial and commercial process applications, and it is anticipated that the Department of Defense (DOD) installations will join in this trend over the next decade. Public and private development efforts over the past few years have resulted in gas energy conversion technologies with improved efficiencies, reduced emission levels, and lower life cycle costs. Advanced natural gas technologies such as ultra-low emission burners, gas turbines, and natural gas cooling systems are likely to play an increasingly important role at DOD facilities.

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Foreword

This study was conducted for the Office of the Deputy Assistant Secretary of Defense (Installations), under Military Interdepartmental Purchase Request (MIPR) No. DSAM50060, "DOD Natural Gas Utilization Study." The technical monitor was Millard Carr, DASD(I).

The work was performed by the Utilities Division (UL-U) of the Utilities and Industrial Operations Laboratory (UL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was William R. Taylor. The Institute of Gas Technology (IGT) was contracted to identify performance criteria of selected current and advanced natural gas technologies applicable to DOD installations under Indefinite Delivery Contract Number DACA8894D0014. Yusaf Shikari and Mark Richards are associated with the Institute of Gas Technology, Des Plaines, IL. Martin J. Savoie is Acting Chief, CECER-UL-U; John T. Bandy is Operations Chief, CECER-UL; and Gary W. Schanche is the associated Technical Director, CECER-UL. The USACERL technical editor was William J. Wolfe, Technical Resources.

COL James A. Walter is Commander and Dr. Michael J. O'Connor is Director of USACERL.

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1 Introduction

Background

Recent changes in energy prices, an emphasis on low emissions, and availability of energy-efficient technologies have resulted in Federal energy policies that promote the increased use of clean-burning natural gas for heating, cooling, power generation, transportation, and other industrial and commercial process applications. It is envisioned that the Department of Defense (DOD) installations will also join in this trend over the next decade. Public and private development efforts over the past few years have resulted in gas energy conversion technologies with improved efficiencies, reduced emission levels, and lower life cycle costs. Advanced natural gas technologies such as ultra-low emission burners, gas turbines, and natural gas cooling systems are likely to play an increasingly important role at DOD facilities.

Since nearly 76 percent of over 700 DOD facilities that exist today in the continental United States and Alaska already use natural gas, the facility planner is more likely to adopt an advanced natural gas technology at his/her site (*DEIS* 1990). While the Government has a software tool, entitled Renewables and Energy Efficiency Planning (REEP) program, for evaluating alternative Energy Conservation Opportunities (ECOs) at U.S. military installations, there exists a need to incorporate new and evolving gas-fired energy conversion technologies in its database and, where needed, update evaluation algorithms as well as technical and economic performance characteristics for ECOs included in the current version of the REEP program.

The U.S. Army Construction Engineering Research Laboratories (USACERL) was tasked with identifying important performance criteria of selected current and advanced natural gas technologies applicable to DOD installations.

Objective

The primary objective of this research effort was to provide DOD facility engineers with a set of performance criteria for selected current and advanced

natural gas technologies. These criteria can then be used by the Government to develop technology screening agents for the REEP program. Successful inclusion of these criteria and/or algorithms in the REEP program will allow DOD facility planners to take full advantage of the state-of-the-art gas-fired heating, cooling, power generation, and industrial process technologies and, thereby, optimally expand the use of natural gas at most military installations.

Approach

To support this effort, USACERL enlisted the expertise of the Institute of Gas Technology (IGT). IGT initiated this research effort by preparing and submitting a document to USACERL detailing the overall objective, technical scope of work, deliverables, and schedule. IGT worked with USACERL researchers to develop and implement the project plan summarized below:

- *REEP Program Overview* - This part of the project was devoted to a detailed review of the current version of the REEP program. It specifically included installation of the REEP program at IGT facilities; an analysis of input data requirements and algorithms used for evaluation of various gas technologies; an examination of the *Defense Energy Information System (DEIS)* — Office of the Under Secretary of Defense (Production and Logistics), Publication DOD 5126.46-M, February 1990 technology- and military installation-specific data and relevant assumptions; an understanding of various analysis and output reporting options available to the user; and an execution of the program to run selected simple and financial analyses. Chapter 2 is devoted to the results of this in-depth review and discusses the relevance of the REEP program to the overall research effort.

- *Advanced Natural Gas Technologies Review* — This task focused on a comprehensive assessment of state-of-the-art in advanced natural gas technologies for space heating, space cooling, dehumidification, power generation, and industrial process applications. IGT conducted a detailed literature search and contacted major manufacturers to complement its extensive database to arrive at a portfolio of commercially available and soon-to-be-deployed advanced gas technologies applicable to DOD installations. To the extent feasible, information on relevant cost and performance parameters was obtained. Finally, a comparative analysis of similar technologies for each of the major applications mentioned above was conducted to identify their features, advantages, and constraints relative to one another. Results from this task are detailed in Chapter 3.

- *Natural Gas Technology Screening Criteria Summary* – This task emphasized natural gas technology- and installation-related parameters and factors that one must examine before implementing a particular technology at a given DOD facility. Relevant economic and infrastructure issues were also addressed. Further details on this summary can be found in Chapter 4.

- *Energy Conservation Opportunities (ECO) Description* – This segment of the research effort concentrated on specific advanced natural gas technologies selected for implementation into the REEP program. Detailed ECO descriptions for each selected technology were developed and categorized in terms of their potential application markets (e.g., family housing, building HVAC systems, utilities heating and cooling plants, commercial, and industrial). Based on an in-depth examination of relevant evaluation algorithms in the current version of the REEP program, IGT developed suggestions for additions/changes to input parameters and/or energy usage and savings calculation relationships for selected ECOs. Chapter 5 focuses on this topic.

- *Standard REEP Output for Natural Gas Technologies* — The modified and newly developed natural gas algorithms were incorporated into REEP. Chapter 6 gives the results obtained using REEP to apply the natural gas algorithms to DOD installations.

- *REEP Analysis and Results* – Appendix A of this report provides illustrative examples of REEP analysis and results for a number of selected ECOs. A summary of system-wide impacts of implementing all these ECOs has also been presented here. This analysis was done before development of new ECOs and before incorporating algorithms into the REEP program. (Chapter 6 gives an analysis using the new algorithms in REEP.

- *Discussion on Cooling Season-Related Data in REEP* – A detailed discussion on possible anomalous treatment of full load cooling hours data in the current version of the REEP program is given in Appendix B.

- *Current REEP ECO Algorithms* – So that suggested ECO algorithm changes can be understood better, all applicable ECO algorithms from the current version of the REEP program are listed as a reference in Appendix C.

- *Field Visits Report* – This segment of the project included site visits to three DOD installations – Fort Eustis, VA, Fort Hood, TX, and Fort Riley, KS – to verify/update relevant input data for these facilities, to compare the

assumptions made in the relevant ECO algorithms with actual conditions, and to obtain the facility engineer/planner's feedback so that potential benefits of implementing advanced natural gas technologies at these DOD installations could be optimally realized. Results of IGT's field verification efforts at the above mentioned three sites are given in Appendix D.

- *Conclusions and Recommendations* – Chapter 7 of this report highlights key results of the overall research effort and provides suggestions for future research, REEP program modification, etc.

2 Renewables and Energy Efficiency Planning (REEP) Program Overview

General

The Renewables and Energy Efficiency Planning (REEP) program was developed at the United States Construction Engineering Research Laboratories (USACERL) with funding from the DOD, the Department of Army (DA), and the Strategic Environmental Research and Development Program to provide users with a flexible analytical tool for evaluating relative merits of implementing alternative Energy Conservation Opportunities (ECOs) at United States Army installations. The REEP program uses a series of technology evaluation algorithms in conjunction with installation specific data to estimate energy conservation potential as well as economic, environmental, and social benefits for entire installations. These estimates of DOD-wide savings and benefits are then considered during budget development and program planning for future years.

The REEP program was developed using Microsoft FoxPro Version 2.5 for Windows™. FoxPro is a Relational Database Management System with a capability for developing custom applications using its built-in programming language. The program runs on any IBM PC-compatible machine with an 80386 or higher microprocessor, and requires a minimum of four megabytes (MB) of disk space plus an eight MB of RAM. It has been designed to run in a Windows environment and requires Microsoft Windows 3.1 or higher to run properly.

REEP Program Structure

Figure 1 below depicts a simplified flow diagram for the REEP program. A brief description of each block in this diagram follows.

- *Installation Selection:* The first step in the execution of the REEP program is for the user to select one or more DOD installations. The selection of an installation is linked directly to the installation database, which contains site-specific characteristics.

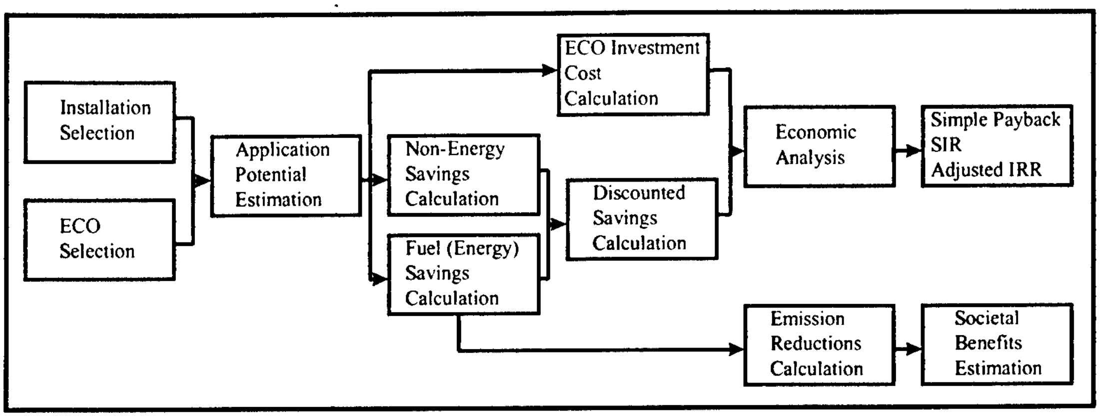

Figure 1. Simplified flow diagram for the REEP program.

- *ECO Selection:* Selection of a particular ECO activates corresponding ECO program files and an ECO database file. Each ECO program file provides an evaluation algorithm, while the ECO database file contains values and variables unique to that technology.

- *Application Potential Estimation:* Next, the ECO algorithms triggered by the selection of particular ECOs estimate the maximum potential of that application in terms of number of opportunities for each technology. This calculation is usually based on the size or energy delivery capacity of (or square footage applicable to each) unit.

- *Non-Energy Savings Calculation:* This section of the REEP program is devoted to the calculation of savings (or costs) associated with operation and maintenance of a given piece of equipment. Typically, these savings (or costs) are realized on a periodic basis or can be spread uniformly over the useful service life of an ECO being evaluated.

- *Fuel (Energy) Savings Calculation:* A series of algorithms from the program files for each selected ECO are used to calculate appropriate fuel (gas, oil, coal, water, and/or electricity) and demand charge savings on an annual basis. For most ECOs, only one or a few resource savings are applicable. Relevant information from the ECO and installation database files is extracted to perform these calculations.

- *Discounted Savings Calculation:* Nonenergy and fuel (energy) discount factors published by the National Institute of Standards and Technology (NIST) are used to adjust nonenergy and fuel (energy) savings calculations mentioned above (Petersen 1996; Petersen [NISTIR] 1995).

- *ECO Investment Cost Calculation:* The total installed cost of implementing a particular ECO at a given DOD installation is calculated by multiplying the adjusted unit cost of that ECO with the number of opportunities estimated earlier. The adjusted unit cost reflects the first cost of the technology, applicable quantity discount, and regional installation cost variations. If more than one ECO is involved, the investment cost of each ECO is used to arrive at the total construction cost for the project.

- *Economic Analysis:* The Energy Conservation Investment Program (ECIP) criteria within the REEP program are used to calculate a number of economic indicators such as simple payback, savings-to-investment ratio (SIR), and adjusted internal rates of return (AIRRs). These economic indicators are then compared with pre-established criteria to evaluate economic viability of an ECO (or a project) being considered.

- *Emission Reductions Calculation:* Two distinct sets of algorithms are used to calculate emission reductions – one set determines the amount of pollution offset on-site based on the type of fossil fuel used for a given ECO and the other set estimates the net impact of purchased electricity on emissions.

- *Societal Benefits Estimation:* Certain societal benefits can be attributed to reductions in pollution generation rates. The REEP program uses the societal cost numbers from a study conducted by the Pace University to arrive at this estimation (Ottinger et al. 1990).

Input Requirements

The current version of the REEP program requires over 100 specific data entries for each DOD installation and a set of algorithms for each ECO being evaluated. The user then evaluates the ECO(s) of interest at his/her selected DOD installations. The current version of the REEP program allows for the analysis of 83 ECOs at 242 military installations (110 Army, 69 Air Force, and 63 Navy). A detailed listing of these ECOs and DOD installations is provided in the REEP Program Manual, which was published by USACERL in 1995 (Nemeth 1995).

Installation specific data includes basic demographic information such as location, type of service, population, etc., as well as detailed characterization of the facility in terms of building types and sizes, capacities of heating and cooling equipment, utility rates, weather-related information, distribution of electricity produced by various primary energy sources, energy consumption, emissions,

and market penetration rates for each ECO. Some of this information is readily available from published sources such as the *Facilities Engineering and Housing Annual Summary of Operations - Volume III - Installation Performance*, commonly known as the "Red Book" (USAEHSC 1993). The weather data is derived from Engineering Weather Data (Department of the Army [DA] Technical Manual) and other miscellaneous sources (DA 1978).

As for ECOs, the current version of the REEP program divides them into the following eight basic categories: lighting, electrical, building envelope, HVAC, water, utilities, renewables, and miscellaneous. Since this research effort focused exclusively on natural gas technologies, only two of these eight categories (HVAC and utilities) are emphasized in the rest of this report. ECO specific data include size/capacity, cost and performance parameters, applicability to various building types, etc., and are embedded into each ECO evaluation algorithm as assumptions.

Analysis Options

Four basic analysis options are available to the users of the current version of the REEP program:

1. A simple analysis
2. A financial summary analysis
3. A resource summary analysis
4. A pollution summary analysis.

A simple analysis, as the name implies, just compares competing technologies to one another, i.e., it evaluates the effects of implementing a given ECO at each selected DOD installation. Thus, if X number of ECOs were to be evaluated for Y number of DOD installations, the simple analysis option would yield X*Y sets of results. These sets of results can then be compared either to rank X number of ECOs at one specific installation or to identify those DOD installations where a particular ECO would have the greatest economic, environmental, and societal impact. It should, however, be noted that the user's selection of the simple analysis option does not allow him/her to filter out any overlapping technologies (e.g., retrofit applications). All of the summary analyses, on the other hand, consider only the best of all overlapping technologies as determined by the user-specified selection criteria. Thus, for a given set of ECOs and/or DOD installations, the algebraic summation of the results from a simple analysis will

not always compare exactly to those from either of the three summary analyses listed above.

Since the summary analysis can be performed to summarize only the financial, resource, or pollution information resulting from the previously run simple analysis, the user must first perform a simple analysis before selecting any summary analysis option. The financial summary analysis yields ECO specific information on number of units, total investment, total net discounted savings, simple payback, SIR, AIRR, and societal savings for a set of selected DOD installations. The resource summary analysis is used to develop ECO specific demand and energy (fuel) savings for selected military sites. Similarly, the pollution summary analysis provides ECO specific estimates of emission reductions for selected DOD facilities.

The current version of the REEP program allows both numerical and graphical display of results of each analysis options. If desired, the user can also generate a composite summary report for selected ECOs/installations to obtain information at a macro level. The composite summary report also provides a comparison of current energy consumption with that in the past.

Benefits of Program

The REEP program is a user-friendly computer program that can be used by both installation energy managers and budget analysts. Energy managers can use it to assess the relative merits of existing ECOs at their facilities and focus on those that provide the greatest beneficial impact in coming years. REEP can assist budget analysts develop long-term strategic plans for implementing promising ECOs at various DOD installations.

The REEP program provides the user with a broad overview of energy savings potential and associated economic, environmental, and societal benefits at an installation level. While this program is not intended to replace other effective engineering analytical tools that help in the evaluation of specific ECOs at particular buildings within a given DOD installation, an informed user, to a limited extent, can obtain initial estimates and guidance with a minimum of data requirements and effort.

Finally, REEP calculated costs for conservation can be used as justification for the establishment of future funding streams targeted for conservation efforts to comply with Federal Government mandates.

3 Advanced Natural Gas Technologies Review

Natural Gas ECOs in REEP

As mentioned in the preceding chapter of this report, the current version of the REEP program allows screening and evaluation of over 80 ECOs in eight basic categories. These technologies represent natural gas, oil, coal, electricity, water, solar, and/or wind as their primary energy source(s). All natural gas-fueled technologies are included in the REEP program under either the "Heating/ Cooling" or "Utilities" category. Table 1 lists all of the natural gas technologies represented in the current version of the REEP program.

Table 1. Natural gas ECOs in the current version of the REEP program.

ECO Category*	Natural Gas Technology	Units
Heating/Cooling	Desiccant Cooling	Units
	Enthalpy Recovery Desiccant Wheel	Wheels
	Family Housing Gas Engine-Driven Heat Pump	Heat Pumps
	Family Housing High-Efficiency Gas Furnace	Furnaces
	Family Housing Nominal-Efficiency Gas Furnace	Furnaces
	Gas High-Efficiency Boiler	Boilers
	Gas Nominal-Efficiency Boiler	Boilers
Utilities	Cogeneration - Phosphoric Acid Fuel Cell	Fuel Cells
	Cogeneration - Gas Turbine	Turbines
	Cogeneration - Reciprocating Engine	Engines
	Direct-Fired Gas Absorption Chiller (5 to 50 Tons)	Chillers
	Direct-Fired Gas Absorption Chiller (50 to 100 Tons)	Chillers
	Direct-Fired Gas Absorption Chiller (>100 Tons)	Chillers
	Gas Engine-Driven Air Compressor	Engines
	Gas Engine-Driven Chiller (5 to 50 Tons)	Chillers
	Gas Engine-Driven Chiller (50 to 100 Tons)	Chillers
	Gas Engine-Driven Chiller (>100 Tons)	Chillers

* Source: Nemeth (1995).

Proposed Natural Gas ECOs for REEP

Numerous advanced natural gas technologies with potential for application at DOD installations have been made available in the marketplace in recent years, and several other enhancements are nearing development. To make the evaluation of relative merits of these emerging gas technologies more effective and better focus on target applications at DOD installations, it is suggested that ECO categories currently in the REEP program be reorganized by the following market application segments:

- Family Housing (or Residential) HVAC Systems
- Building HVAC Systems
- Utilities and Heating/Cooling Plants
- Industrial/Process Applications.

A comprehensive literature search of recently commercialized advanced natural gas technologies was conducted and major manufacturers of these equipment and products were contacted to update and further enhance our extensive database. The primary focus of this exercise was on features and advantages/ constraints of applicable advanced natural gas technologies for space heating, space cooling, power generation, and industrial process applications. They are segmented by their applicable markets, viz., family housing (or residential), light commercial, commercial, and large commercial/industrial. Desiccant systems are further separated into three applications – enthalpy recovery wheel, dehumidification system, and sensible and latent cooling equipment. High efficiency gas furnaces of three types are considered – recuperative, condensing, and pulse combustion. Finally, utilities and heating/cooling plants of multiple sizes are considered to enable more targeted evaluation of their relative merits for potential implementation at DOD installations.

The current version of the REEP program does not have any ECOs for industrial/ process applications. A number of emerging and state-of-the-art natural gas technologies in this category have been added as ECO candidates for inclusion in the REEP program. Table 2 lists these advanced natural gas technologies by ECO categories suggested above.

Table 2. Advanced natural gas ECO candidates for inclusion in the REEP program.

ECO Category	Advanced Natural Gas Technology	Units
Family Housing HVAC Systems	Desiccant Cooling - Dehumidification System (< 5 RT,)	Dehumidifiers
	Desiccant Cooling - Sensible and Latent Cooling (< 5 RT)	Units
	Gas-Engine-Driven Heat Pump	Heat Pumps
	High-Efficiency Gas Furnace, Recuperative	Furnaces
	High-Efficiency Gas Furnace, Condensing	Furnaces
	High-Efficiency Gas Furnace, Pulse Combustion	Furnaces
Building HVAC Systems	Desiccant Cooling - Dehumidification System (5 to 25 RT)	Dehumidifiers
	Desiccant Cooling - Dehumidification System (25 to 100 RT)	Dehumidifiers
	Desiccant Cooling - Dehumidification System (> 100 RT)	Dehumidifiers
	Desiccant Cooling - Sensible and Latent Cooling (5 to 25 RT)	Units
	Desiccant Cooling - Sensible and Latent Cooling (25 to 100 RT)	Units
	Desiccant Enthalpy Recovery Wheel (5 to 25 RT)	Wheels
	Infrared Radiant Heating System	Units
Utilities and Heating/ Cooling Plants	Cogeneration - Gas Turbine (< 5 MW)	Turbines
	Cogeneration - Gas Turbine (5 to 20 MW)	Turbines
	Cogeneration - Phosphoric Acid Fuel Cell	Fuel Cells
	Cogeneration - Reciprocating Engine (< 100 kW)	Engines
	Cogeneration - Reciprocating Engine (100 to 500 kW)	Engines
	Cogeneration - Reciprocating Engine (500 kW to 2 MW)	Engines
	Cogeneration - Reciprocating Engine (> 2 MW)	Engines
	Direct-Fired Gas Absorption Chiller (< 5 RT)	Chillers
	Direct-Fired Gas Absorption Chiller (5 to 25 Tons)	Chillers
	Direct-Fired Gas Absorption Chiller (25 to 100 Tons)	Chillers
	Direct-Fired Gas Absorption Chiller (>100 Tons)	Chillers
	Gas Engine-Driven Air Compressor	Engines
	Gas Engine-Driven Chiller (5 to 25 Tons)	Chillers
	Gas Engine-Driven Chiller (25 to 100 Tons)	Chillers
	Gas Engine-Driven Chiller (>100 Tons)	Chillers
	High-Efficiency Gas Boiler (< 100 hp)	Boilers
	High-Efficiency Gas Boiler (100 to 250 hp)	Boilers
	High-Efficiency Gas Boiler (> 250 hp)	Boilers
Industrial/ Process Applications	Composite Radiant Tube	Tubes
	Fuel Based Nitrogen Generator	Generators
	Low-Inertia Heat-Treating Furnace (Flat Plate Heater)*	Furnaces
	Medical Waste Treatment System	Units
	Mineral Wool Melter*	Units
	Oscillating Combustion Technology*	Valves
	Oxygen-Enriched Air Staging System for Regen. Glass Furnaces	Units
* Emerging technologies - Not yet commercially available		

For all commercially available advanced natural gas technologies, pertinent product literature was reviewed and respective manufacturers (or their representatives) were contacted to obtain updated information on each equipment's or system's technical and economic parameters and to ascertain their applicability to DOD installations. For those technologies still being developed, relevant research organizations and/or commercialization partners

were contacted to compile the data on expected market entry date, design performance parameters, range of size/capacity, likely first cost, advantages/disadvantages relative to equipment/product(s) currently being used, etc. As a result, a comprehensive portfolio of commercially available – and soon to be marketed – advanced natural gas technologies for space heating, space cooling, cogeneration, and industrial/process applications with potential for implementation at DOD installations has been developed.

Family Housing and Building HVAC Systems

There are a number of advanced natural gas HVAC systems currently available in the marketplace. These are comprised of desiccant systems, gas engine-driven heat pumps, high-efficiency gas furnaces, and infrared radiant heating systems.

High-Efficiency Gas Furnaces and Gas Engine-Driven Heat Pump

For gas furnaces, three types of high-efficiency units are available: recuperative (seasonal efficiency: 85 percent), condensing (seasonal efficiency: 92 percent), and pulse combustion (seasonal efficiency: 94 percent). Major manufacturers of these high-efficiency units include American Standard, Bryant, Carrier, Coleman, Lennox, Trane, and York. One of the most active areas of research and development is heating and cooling systems for family housing and light commercial applications. At present, York International Corporation is the only United States company that markets a gas engine-driven heat pump under the brand name Triathlon™. Other manufacturers involved with natural gas HVAC systems include Columbia Gas Distribution Companies and Wave Air Corporation.

Desiccant Systems for Dehumidification, Sensible and Latent Cooling, and Enthalpy Recovery

Desiccant systems can be divided into three categories – dehumidification systems, enthalpy recovery wheels, and latent and sensible cooling systems. Desiccant dehumidification systems control humidity levels directly, thereby, allowing users to separate humidity control from temperature control. These systems are well suited for supermarkets, health spas, hotels, offices, medical facilities, and restaurants. Desiccant systems are particularly effective when the latent heat load is proportionately higher than the sensible heat load. For cooling applications, the dried air exiting from the desiccant material is cooled to the desired level with an air-to-air heat exchanger, an evaporator cooler, or a

cooling coil. Desiccant systems can also be used very effectively to pre-condition humid make-up air before it enters a building. This helps increase fresh air flow and, thereby, improve indoor air quality. Recent advances in desiccant wheel technology have added the ability to handle sensible cooling through return air heat exchange and controlled resaturation. Research in desiccant wheel technology continues with an emphasis on the development of advanced desiccant materials and cost-effective improvements in manufacturing processes.

Figure 2 below depicts a schematic of a rotating wheel desiccant dehumidification system. Outside humid air or return air or a combination of both is passed over the desiccant wheel at point A. The dry air exiting the wheel is then passed through a heat exchanger at point B, where heat from the hot air is transferred to the regeneration air stream. If the desiccant system has an evaporative cooling option, dry air stream passes through a direct evaporative cooler at point C, where the sensible temperature of air is reduced before it is fed into the conditioned space. The regeneration air stream – which can be either outside air or return air – enters the unit at point D.

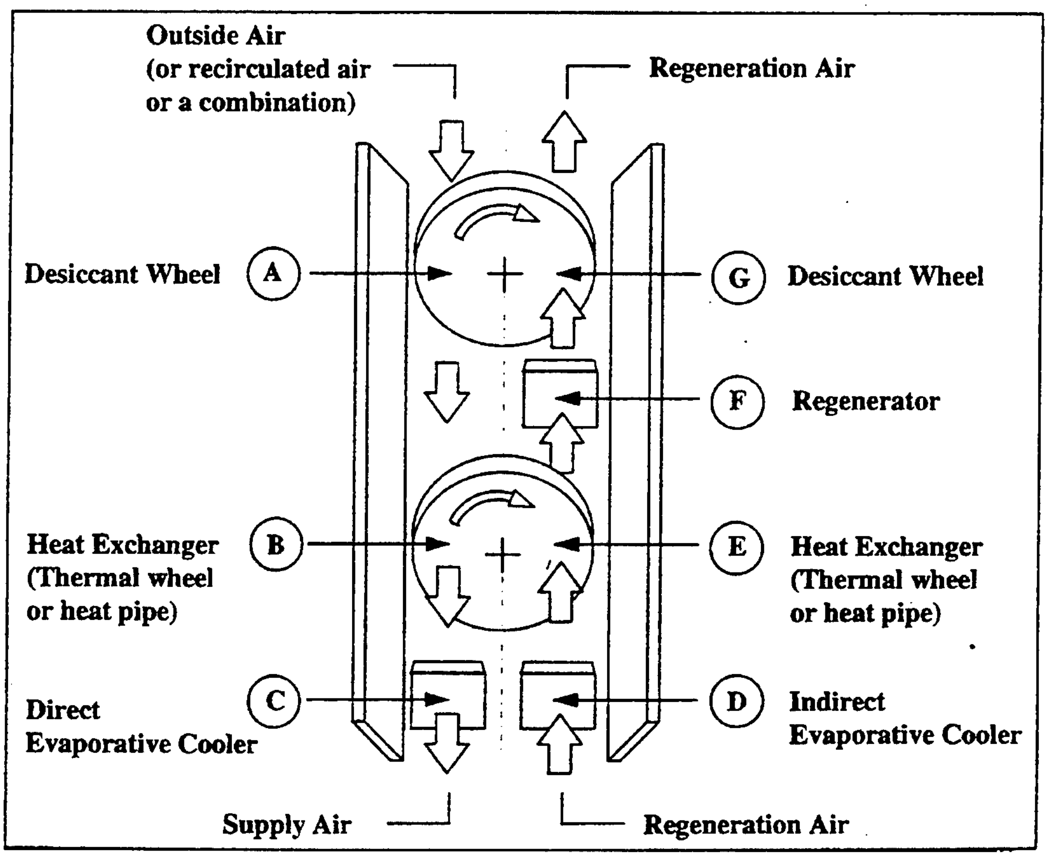

Figure 2. Schematic diagram of a desiccant dehumidification system with evaporative cooling.

Once again, if an evaporative cooling is used, the regeneration air stream is cooled as it passes through an evaporator before entering the heat exchanger at point E. Next, this air stream is heated in the regenerator at point F. As the hot regeneration air is sent through the desiccant wheel at point G, it pulls the moisture out of the desiccant wheel. The moist regeneration air is rejected into an outside atmosphere. Finally, since the basic operating principle of a desiccant system is vastly different from that of a conventional cooling system, it cannot be used as a direct substitution for electric or absorption or engine-driven cooling systems on a ton-for-ton basis. Major manufacturers of desiccant systems in the United States include Airflow Company, Comfort Enterprises, Engelhard/ICC, Kathabar, Munters Corporation, LaRoche Air Systems, New Thermal Technologies, Octagon Air Systems, and SEASONS. Table 3 gives a detailed listing of commercially available natural gas desiccant systems.

Infrared Radiant Heaters

Buildings isolated from an installation's central heating network use about half of the Army's heating energy. The use of conventional heating technologies does not offer an optimum solution especially in hanger facilities where there exists a large amount of open space. Infrared radiant (IR) heating systems are ideal for such applications.

Table 3. Commercially available natural gas desiccant systems.

Desiccant System*		Capacity (cfm)
Standard Desiccant Systems:		
1.	DRYOMATIC Drycell Dehumidification System	1,000 to 20,000
2.	Engelhard/ICC DESI/AIR™	5,000 to 25,000
3.	Engelhard/ICC DESERT COOL™	1,500 to 6,500
4.	Kathabar Kathapac® Dehumidifier	1,000 to 84,000
5.	Cargocaire HCD Plus Dehumidifier	300 to 12,000
6.	Cargocaire IDS Integrated Dehumidification System	400 to 80,000
7.	Cargocaire HCE Large-Scale Modular Dehumidifier	9,000 to 40,000
8.	Munters DryCool® SuperAire System	5,000 to 10,000
9.	Munters DryCool® IceAire System	5,000 to 10,000
10.	Munters DryCool® MedAire System	5,000 to 10,000
11.	Munters DryCool® MakeupAire System	5,000 to 10,000
12.	New Thermal Technologies Latent Air Conditioner	500 to 2,000
13.	Octagon Desiccant Air Conditioner	5,000 to 10,000
14.	SEASONS•4 Desiccant System	5,000 to 10,000
15.	SEASONS•4 Desiccant System with Evaporative Cooling	4,000 to 16,000
Desiccant Dehumidifier:		
1.	Comfort Enterprises Company's The Comfort Solution™	165
* Source: The American Gas Cooling Center, Inc. (April 1996).		

A number of DOD installations have realized significant cost and energy savings by implementing this technology. The state-of-the-art system typically is sealed, maintenance-free, vacuum vented, and features aluminized steel tubing for long life and dry tube construction to eliminate corrosive condensation. It is also capable of zone control. Besides hangers, IR heaters are suitable for factories, warehouses, recreational facilities, and gymnasiums.

Utilities and Heating/Cooling Plants

As mentioned earlier, it is suggested that the following natural gas technologies be considered for inclusion in the next version of the REEP program under the "Utilities and Heating/Cooling Plants" ECO category:

- High-Efficiency Gas Boilers
- Phosphoric Acid Fuel Cells
- Gas Absorption and Engine-Driven Chillers
- Gas Engine- and Turbine-Driven Cogeneration Systems
- Gas Engine-Driven Air Compressors.

High-Efficiency Gas Boilers

Buildings isolated from an installation's central heating network represent a significant portion of the Army's heating energy needs. Replacing the old boilers in these buildings with new high-efficiency, low-emission boilers could reduce fuel usage and costs significantly. Buildings best suited to conversion are those that have gas-fired boilers in the size range of 1.0 to 3.0 million Btu/hour of output. Major manufacturers of firetube, watertube, and hybrid gas-fired steam boilers in the United States include ABB, Babcock & Wilcox, Chromalox, Clayton Industries, Cleaver-Brooks, Combustion Systems, Detroit Stoker, Donlee, Empire, Fulton, Hurst, Industrial Air Systems, Parker, and Tampella Power – just to name a few (Thomas Register 1996). Most of these manufacturers offer products that are suitable for both new and retrofit applications. Advanced technology features incorporated into some of the high-efficiency boilers range from a hybrid firetube/watertube approach to cyclonic combustion and from modular designs to very low NOx emissions.

Phosphoric Acid Fuel Cells

Many applications require both electricity and thermal energy. Central energy plants are a prime application at DOD facilities. The ability of fuel cells to produce electricity in an extremely clean manner (no combustion is involved in its electrochemical process) makes it ideal for situations when reliable backup power is required and in areas where air quality would prevent other power generation technologies from being allowed. At present, the only commercially available fuel cell power plant is a 200 kW phosphoric acid fuel cell. This technology can operate in parallel with the utility grid or in an independent mode. Since fuel cells, at current manufacturer's suggested price of $3,000/kW, are only marginally cost effective, the U.S. Government has instituted a rebate program – equivalent to about $1,000/kW – to facilitate accelerated deployment of fuel cells in the marketplace.

Gas Absorption and Engine-Driven Chillers

As for cooling plants, two basic types of gas chillers are commercially available at present – absorption and engine-driven. Each type is marketed by multiple vendors in standard packages that have proven reliable and cost-effective for a variety of applications. If desired, most manufacturers are capable of providing larger units and/or custom configurations as well as designing absorption systems that can be combined/packaged with cogeneration systems.

Gas Absorption Chillers. Commercially proven absorption systems that are readily available in the market today range in size from 3 to 1,700 refrigeration tons (RT). They are available as chillers or chiller/heaters. Absorption systems can be divided into two types: *Direct-Fired* by a gas burner integral to the unit or *Indirect-Fired* by an external power source such as steam, hot water, or waste heat from a cogeneration system or an industrial process. Further, they can be either of a single-effect or a double-effect variety. Double-effect absorption units have a second generator and condenser that operate at a higher temperature, and produce the same cooling effect as that from a single-effect unit for a fraction of the heat input. Research continues to further improve the coefficient of performance (COP) of gas absorption chillers. The next significant performance breakthrough will come when the triple-effect absorption units will be introduced in the marketplace.

All direct-fired gas absorption chillers operate very similar to conventional vapor compression chillers, except that they use water or ammonia rather than standard Chlorofluorocarbon (CFC) refrigerants, require a second fluid (such as

lithium bromide for water-cooled systems or water for air-cooled systems) as the absorbent material, operate at low pressure/vacuum conditions, and employ heat – and not a compressor – as their driving force. Figures 3 (The American Gas Cooling Center, Inc., April 1996) and 4 below highlight key differences between a vapor compression cycle and a single-effect absorption cycle. For gas absorption systems, a mechanical compressor (shown as a dotted box in Figure 3) component of a vapor compression cycle is replaced with what is generally called a thermal compressor (shown as a dotted box in Figure 4). It consists of a generator to boil the refrigerant, a pump to raise the solution pressure from the lower evaporating pressure to the higher condensing pressure, and an absorber to release the heat of condensation and heat of mixing. To improve the efficiency of the cycle shown in Figure 4, a heat exchanger is also incorporated into the thermal compressor (usually placed between the pump and the generator).

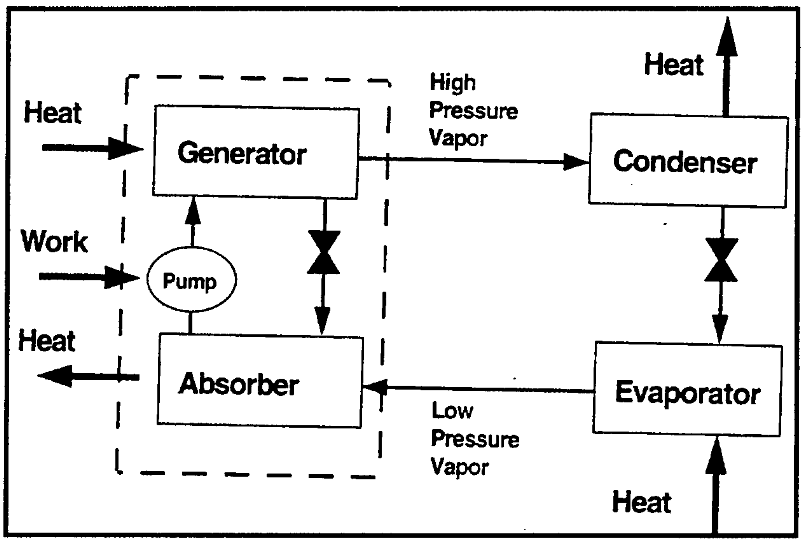

Figure 3. Vapor compression cycle.

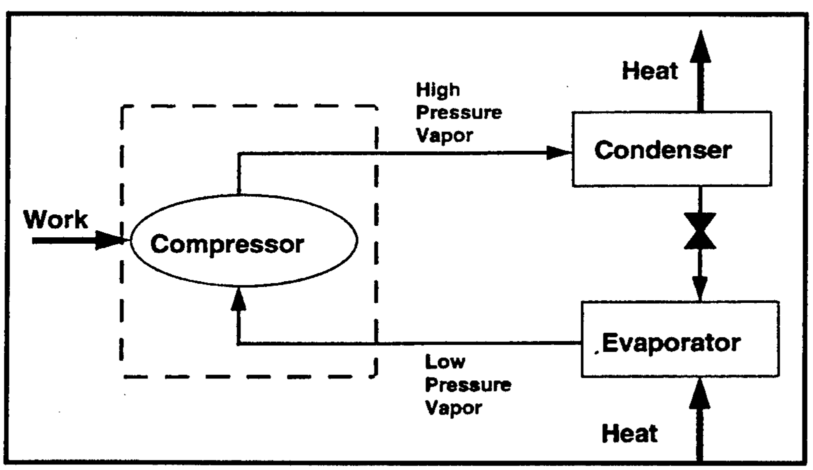

Figure 4. Single-effect absorption cycle.

Gas absorption systems offer a number of advantages over conventional electric systems, which include, but are not necessarily limited to:

- low operating costs
- absence of ozone damaging refrigerants (use of water or ammonia as the refrigerant)
- high reliability (use heat – and not compressor – as driving force)
- low maintenance
- reduced noise level (no large rotating components)
- enhanced safety (lower operating pressure)
- reduced space requirement (when compared to electric chiller/separate boiler configuration).

Table 4 gives a detailed listing of commercially available natural gas absorption systems.

Table 4. Commercially available natural gas absorption systems.

Absorption System*		COP+	Capacity (RT)
Direct-Fired Absorption Systems (includes integrated burner)			
1.	American Yazaki V-Series Double-Effect Chiller/Heater	1.00	30 to 100
2.	Carrier Double-Effect Chiller/Heater	0.97	135 to 1,000
3.	Dunham-Bush Iron Fireman® Double-Effect Chiller	---	240 to 550
4.	McQuay Double-Effect Modular Chiller/Heater	0.95	20 to 80
5.	McQuay Double-Effect Chiller/Heater	1.00	100 to 1,500
6.	ServelSM Single-Effect Chiller/Heater	0.48 to 0.62	3 to 5
7.	ServelSM Single-Effect Chiller	0.48 to 0.62	3 to 25
8.	Trane Horizon™ Double-Effect Chiller	1.01	380 to 500
9.	Trane Thermachill™ Double-Effect Chiller	0.97 to 1.04	100 to 1,100
10.	York® Millenium™ Double-Effect Chiller/Heater	0.92 to 1.00	120 to 1,000
Indirect-Fired Absorption Systems (powered by steam, hot water, or waste heat):			
1.	American Yazaki Single-Effect Chiller	0.60 to 0.70	5 to 10
2.	Carrier Double-Effect Chiller	1.20	100 to 1,700
3.	Carrier Single-Effect Chiller	0.70	100 to 680
4.	Dunham-Bush Iron Fireman® Double-Effect Chiller	---	100 to 1,400
5.	Dunham-Bush Iron Fireman® Single-Effect Chiller	---	100 to 1,400
6.	McQuay Double-Effect Chiller	1.20	100 to 1,500
7.	Trane™ Double-Effect Chiller	1.21	385 to 1,060
8.	Trane™ Single-Effect Chiller	0.68	112 to 1,660
9.	York® Millenium™ Double-Effect Chiller	1.16 to 1.19	600 to 1,500
10.	York® Millenium™ Single-Effect Chiller	0.69	120 to 1,377
+	All COP ratings are based on fuel higher heating value (HHV)		
* Source: The American Gas Cooling Center, Inc. (April 1996).			

Gas Engine-Driven Chillers. Natural gas engine-driven cooling systems use a mechanical process that is very similar to electric cooling systems, except for the fact that an electric motor is replaced with a high-efficiency natural gas engine to drive their reciprocating, rotary screw, or centrifugal compressors. In addition, the gas cooling systems' engine and exhaust heat can be recovered to produce hot water or process steam. Commercially available gas engine-driven cooling plants include packaged water chillers and direct expansion (DX) units.

Current research efforts focus on the development of small gas engine-driven heating and cooling plants targeted for family housing and light commercial markets. The York Triathlon™ gas engine-driven heat pump is the first of these advanced technologies to be introduced into the residential marketplace.

Most of the commercially available gas engine-driven water chillers employ a conventional vapor compression cycle. A vapor compression system typically includes a compressor, a condenser, an expansion valve, and an evaporator. Gas engine-driven chillers are used to cool a chilled water stream, which is then sent to individual air coils, which, in turn, cool and humidify the air being delivered to the space to be conditioned. Three types of compressors are used depending on the size of applications – reciprocating compressors for smaller applications (< 200 RT), rotary screw compressors for mid-size applications (100 to 1,250 RT), and single- or multi-stage centrifugal compressors for large applications (100 to 10,000 RT). Table 5 gives a detailed listing of commercially available natural gas engine-driven chillers.

Gas Engine- and Turbine-Driven Cogeneration Systems

Cogeneration is generally defined as the sequential use of a primary energy source to produce two useful forms of energy – heat and power. It is an opportunity to control and reduce energy costs at DOD installations by investing in a high-efficiency power plant on-site. Typically, a cogeneration system takes heat that under normal circumstances would be wasted and uses it to meet some or all of thermal energy needs of a given facility.

Cogeneration systems include: a prime mover, such as a reciprocating engine or a gas or steam turbine, where fuel is converted to mechanical power and heat; a heat recovery system such as an exhaust heat exchanger; a generator or an alternator; a heat rejection system, to be used when the heat available from the prime mover exceeds thermal energy needs; an interconnection between the cogenerator and the energy user; and a control system.

Table 5. Commercially available natural gas engine-driven cooling systems.

Engine-Driven System*		COP+	Capacity (RT)
Standard Engine Chillers:			
1.	Alturdyne Chiller	1.32 to 1.52	25 to 4,000
2.	CHILLCO Chiller	1.61 to 2.08	75 to 1,000
3.	CHILLCO Dual-Skid Chiller	1.73 to 1.97	1,100 to 2,000
4.	Cummins Southwest POWERCHILL Chiller System	1.41	55 to 200
5.	GASAIR Chiller	1.44 to 1.83	50 to 2,000
6.	TECOCHILL® Air-Cooled Condensing Unit Chiller (RT Series)	1.00 to 1.10	43 to 50
7.	TECOCHILL® Air-Cooled Chiller (CH-110-AC, CH-120-AC, CH-240-AC)	0.82 to 0.85	110 to 240
8.	TECOCHILL® Chiller (ST Series)	1.20 to 1.30	125 to 170
9.	TECOCHILL® Chiller (DT Series)	1.20 to 1.30	250 to 350
10.	TECOCHILL® Chiller (HT Series)	1.70	508 to 986
11.	York® Millenium™ Centrifugal Chiller	1.87 to 1.91	400 to 2,100
Packaged Direct Expansion (DX) Systems:			
1.	GASAIR Unitary Chiller	0.98 to 1.10	15 to 200
2.	TRICO Optimizer Rooftop Heating and Cooling System (20 RT)	0.80 to 1.10	20
3.	TRICO Optimizer Rooftop Heating and Cooling System (30 RT)	0.90 to 1.20	30
Heat Pumps:			
1.	York Triathlon™ Heating and Cooling System	1.30 (Part Load)	3 and 3.5

* The American Gas Cooling Center, Inc. (April 1996); All COP Ratings (Except For Heat Pumps) Are At Full Load, And Are Based On Fuel Higher Heating Value (HHV).

The selection of a prime mover for a given cogeneration system at a particular DOD installation will depend on that military facility's total thermal and electrical requirements, equipment and fuel availability, and economics. Generally speaking, reciprocating engines are very efficient and are best suited to applications requiring modules from 45 kW to field-built systems as large as 8 MW. Combustion turbines are available to units as small as 500 kW. However, these smaller units are not as efficient as larger gas turbines (1 MW to 10 MW) or reciprocating engines. Steam turbines are best suited for applications in size exceeding 5 MW. Figure 5 shows efficiency and size ranges of various prime movers.

While the focus of this report is on natural gas cogeneration systems, it should be noted that cogeneration systems have been operated successfully using land-fill gas, sewer gas, and alternative fuels. Natural gas, of course, offers an optimal choice based on its clean-burning characteristics, ready availability, and attractive relative cost. It is suggested that the REEP program consider using two ECOs to represent gas turbine-driven cogeneration systems (<5 MW and 5 to 20 MW), and four ECOs to represent reciprocating gas engine-driven cogeneration systems (<100 kW, 100 to 500 kW, 501 kW to 2 MW, and >2 MW). Major manufacturers of natural gas cogeneration systems include Caterpillar, Fairbanks, Solar Turbines, Tecogen, U.S. Turbine, and Waukesha. Table 6 lists selected commercially available natural gas cogeneration technologies.

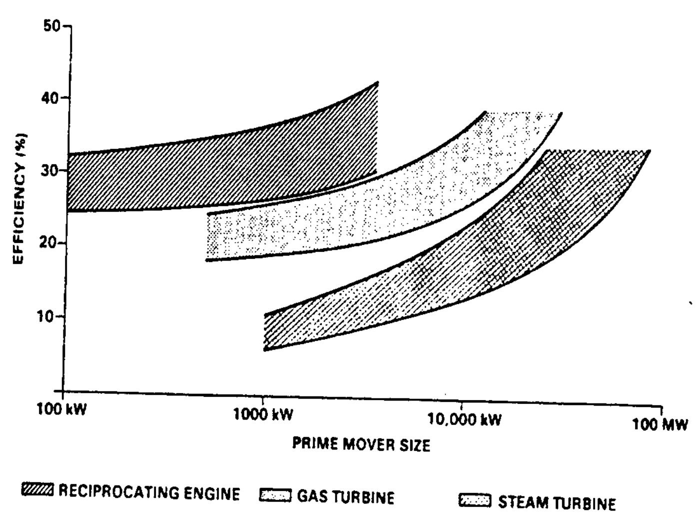

Figure 5. Prime mover efficiency and size ranges.

Table 6. Commercially available selected natural gas cogeneration technologies.

Manufacturer	Model Number	Rating	Engine	Turbine	Remark(s)
	G3412	435	kW	X	A
	G3508	375	kW	X	B
	G3512	600	kW	X	B
	G3516	820	kW	X	B
Caterpillar	G3516TANDEM	1,640	kW	X	B, C
	G3606	1,135	kW	X	D
	G3608	1,515	kW	X	D
	G3612	2,285	kW	X	D
	G3616	3,050	kW	X	D
	38/ 6 Cyl	1,580	kW	X	E
	38/ 9 Cyl	2,370	kW	X	E
	38/12 Cyl	3,165	kW	X	E
Fairbanks	PC2.5/12 Cyl	5,600	kW	X	F
	PC2.5/14 Cyl	6,530	kW	X	F
	PC2.5/16 Cyl	7,465	kW	X	F
	PC2.5/18 Cyl	8,400	kW	X	F
	Saturn 20	1,097	kW	X	
	Saturn T-1500	1,138	kW	X	G
	Centaur 40	3,404	kW	X	
Solar Turbines	Centaur 50	4,219	kW	X	
	Taurus 60	4,849	kW	X	
	Taurus 70	6,145	kW	X	
	Mars 90	9,023	kW	X	
	Mars 100	10,420	kW	X	
Tecogen	CM-60	60	kW	X	H
	CM-75	75	kW	X	H
Waukesha	12VAT27GL	1,753 to 2,458	kW	X	I
	12VAT25GL	1,257 to 2,033	kW	X	I
	8LAT25GL	1,170 to 1,641	kW	X	I
	16V9390GL	858 to 1,538	kW	X	J
	12V7042GL	463 to 1,154	kW	X	J
	12V5790GL	381 to 949	kW	X	J
	12V5115GL	403 to 1,133	kW	X	J, K
	12V5108GL	387 to 837	kW	X	J
	6L3521GL	272 to 576	kW	X	J
	6L2895GL	190 to 474	kW	X	J
	16VP48GL/GLD	500 to 800	kW	X	L
	12VL36GL/GLD	375 to 600	kW	X	L
	8LH24GL/GLD	250 to 400	kW	X	L
	6LF18GL/GLD	185 to 300	kW	X	L
	U.S. Turbine	UST350SG	354	KW	X
	UST560SG	568	kW	X	
	UST600SG	584	kW	X	
	UST700	660	kW	X	
	UST800SG	779	kW	X	
	UST850SG	850	kW	X	
	UST1000SG	955	kW	X	
	UST1100SG	1,134	kW	X	
	UST1200	1,235	kW	X	
	UST1200SG	1,168	kW	X	

Manufacturer	Model Number	Rating	Engine	Turbine	Remark(s)
	UST1400SG	1,416	X		
	UST1500	1,472	kW	X	
	UST1600SG	1,558	kW	X	
	UST1700SG	1,700	kW	X	
	UST1900SG	1,877	kW	X	
	UST2100	2,043	kW	X	
	UST2300SG	2,267	kW	X	
	UST2500CC	2,365	kW	X	M
	UST2800	2,695	kW	X	
	UST3500	3,450	kW	X	
	UST4000	3,944	kW	X	
	UST5000	4,918	kW	X	
	UST5700	5,395	kW	X	N
	UST5800CC	5,787	kW	X	M, N
	UST6600CC	6,392	kW	X	M
	UST9000	8,870	kW	X	O
	UST12000	12,529	kW	X	
	UST15000	14,476	kW	X	
	UST18000	16,880	kW	X	M, P

Remarks: A. Suitable for low jacket water temperature (< 210o F) application
B. Series models with low emission characteristics
C. Best economic value per manufacturer's experience to-date
D. Series models for high temperature (> 265o F) application
E. Opposed-piston EnviroDesign models with low emission (~ 1 gm/bhp)
F. Rated at 514 RPM; 43% thermal efficiency
G. Instant Power Station; potentially most suited for military application
H. Induction motors; most installations in multi-unit tandem configuration
I. ATGL Family models (Large sizes, slowest speeds: 650 to 1000 RPM)
J. VHP Family models (700 to 1200 RPM)
K. VHP Family model, but with little higher speeds (1000 to 1500 RPM)
L. VGF Family models (Small sizes, fastest speeds: 1200 to 1800 RPM)
M. Available with steam re-injection option; most suitable for cyclical heat load application
N. Relatively high thermal efficiency (34% - 35%)
O. Dry low NOx combustion
P. Includes 4"/10" H2O losses

Figure 6 (Waukesha Engine Division, 1996) shows the schematic diagram of a typical natural gas engine-driven cogeneration system. The engine is used to drive an electric generator, and electricity is produced at an efficiency ranging from 25 to 30 percent. Since a cogeneration system is located on-site, nearly half of the fuel's energy can be used to satisfy the end-user's thermal needs by employing an exhaust heat recovery system and an engine coolant heat exchanger.

Natural gas cogeneration systems can also be configured to provide compressed air for process use. Also, recovered heat can be used in an absorption chiller to produce refrigeration. Most gas engine manufacturers, such as Waukesha, have developed integrated factory-assembled modules for cogeneration applications. Modular design allows the end-user to take advantage of cogeneration operating cost reductions without incurring the cost of engineering the entire system.

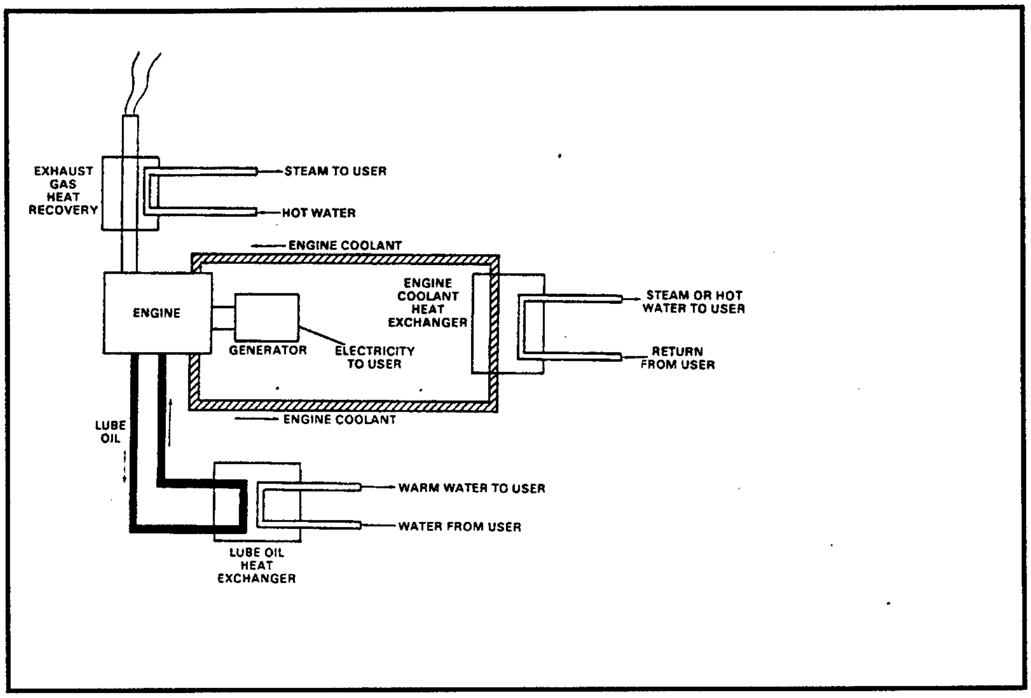

Figure 6. Schematic diagram of a typical gas engine-driven cogeneration system.

The DOD facility planner needs only to concentrate his resources on fuel supply and the electrical and mechanical connections between the module and the end-use equipment. Most factory-assembled cogeneration system modules can easily be located in or near existing mechanical or electrical equipment rooms. To date, thousands of natural gas cogeneration systems have been successfully deployed in hotels, health clubs, hospitals, restaurants, nursing homes, and various industrial facilities throughout the world.

Gas Engine-Driven Air Compressors

Natural gas engine-driven compressors offer advantages of reduced operating costs, high efficiency at part load operations, ability to maintain production during electrical power outages, and waste heat recovery over electric motor-driven compressors. Since the majority of air compressors operate on an as required basis, the use of electric motor-driven units can add significantly to a given DOD installation's peak electrical demand. Gas engine-driven compressors are available in the market in a large range of 30 to 4,000 horsepower and capacities of about 20 to 2,500 cfm (at full-load discharge pressures of 110 to 125 psig). Key players that provide advanced natural gas engine-driven air compressor systems include Col-Weld, Curtis-Toledo, Dearing, Gardner-Denver, GAST, Grimmer-Schmidt, Ingersoll-Rand, LeRoi International, Prime Power, and Quincy. Many of these manufacturers offer an optional heat recovery system that can boost energy efficiencies over 80 percent. For example,

heat recovered from the engine cooling water and exhaust, combined with the heat recovered from the air compressor oil cooler and aftercooler, can be used for heating boiler and laundry process water, unit heaters for space heating, and a variety of other industrial/process applications. Finally, catalytic converters can be installed to meet even the most stringent of local/state emission requirements.

Industrial/Process Applications

In recent years, a variety of advanced natural gas technologies for industrial/process applications has been introduced in the marketplace. These range from glass tempering systems to low NOx burners, from nitrogen generators to pre-packaged compressed natural gas conversion kits, from medical waste treatment systems to innovative heating systems, and from high-temperature vacuum furnaces to compressor diagnostics software. At the same time, research is also continuing to further enhance the technical performance, economics, and regulatory compliance of existing natural gas technologies and to develop new technologies to expand the applicability of natural in the industrial sector of the U.S. economy. These emerging technologies include novel heat treating furnaces, unique approaches to combustion, and advanced materials for industrial burners – just to name a few.

It would be an impossible task to account for all natural gas technology advances of recent years within the limited scope of this research effort. An excellent bibliography of selected advanced natural gas technologies for industrial/process applications is published every quarter by the American Gas Association (A.G.A.) as an educational supplement to *Plant Engineering* magazine.

Based on an evaluation of the site characteristics of DOD installations included in the current version of the REEP program, and personal visits to three representative military bases as a part of this research effort, it is suggested that the following ECOs be considered for inclusion in the next version of the program:

- Composite Radiant Tube
- Fuel Based Nitrogen Generator
- Infrared Radiant Heating System
- Low-Inertia Heat-Treating Furnace (Flat Plate Heater)*
- Medical Waste Treatment System
- Mineral Wool Melter*

- Oscillating Combustion Technology*
- Oxygen-Enriched Air Staging System for Regenerative Glass Furnaces.

Note that an "*" denotes a technology that is still under development. The following paragraphs highlight key features of these advanced commercially available or emerging natural gas technologies for industrial/process applications. Detailed ECO descriptions are provided later in this report (see Chapter 5).

Composite Radiant Tube

The composite radiant tubes (CRTs) are based on silicon and silicon carbide. The primary advantage of CRT is reduced furnace downtime and maintenance due to extended tube life, especially in high-temperature furnaces. Productivity improvement is another significant advantage. CRTs can be fired much hotter than conventional tubes, thereby, providing shorter furnace recovery and overall cycle times when a burner system is optimized to deliver the required heat input. Additional benefits can be realized through electric-to-gas conversions and process improvements. CRTs can be used in all types of batch and continuous heat treating furnaces. At present, CRTs have been successfully deployed in straight, single-pass, and single-ended recuperative tube configurations. Research continues to extend this technology to U-tube applications, which represents a larger share of the market.

Fuel Based Nitrogen Generator

The fuel based nitrogen (FBN) generator technology offers low first as well as operating costs, produces high-purity atmosphere, provides for adjustable hydrogen levels, features high degree of flexibility in operation and maintenance of the system, yields lower NOx emissions, and increases its efficiency through heat recovery. FBN generators are an on-site option for generating nitrogen or nitrogen with controlled percentages (0 to 15 percent) of hydrogen protective atmospheres at a lower cost than those of alternative methods such as fractional distillation, pressure swing adsorption, membrane air separation, or liquid nitrogen. Although the early field applications of FBN generators have been in metals processing, it has a significant potential for other industrial/process applications as well. These include food preservation, pulp and paper production, glass manufacturing, chemicals, and petroleum refining.

Infrared Radiant Heating System

The Directorate of Public Works (DPW) at Fort Eustis has already installed this advanced natural gas technology in seven of its hanger facilities, and savings of more than 30 percent in fuel cost alone have been realized. This low-intensity, vacuum-vented, infrared radiant heating system provides users with unparalleled comfort, dust and draft reduction, and dramatic energy savings. It features low-mass, totally aluminized steel tubular system with solid-state controls and differential air flow switch at each burner.

Low-Inertia Heat-Treating Furnace (Flat Plate Heater)

This innovative technology employs self-recuperating gas-fired flat metallic indirect radiant heaters. These heaters replace the furnace refractory lining and isolate the combustion products from the protective gas atmosphere while increasing the radiant surface area. Increased radiating surface area allows operation at a lower temperature and, consequently, at lower NOx levels. In other words, the useful life of the furnace is prolonged for the same production rate. Uniform lower temperature and a larger radiating surface also improve the uniformity of the load temperature and product quality. Last, but not least, the self-recuperation feature – the use of combustion air to cool the burner's outer surface – increases the thermal efficiency of the unit to more than 70 percent. Figure 7 shows a schematic for the flat plate heater (Erinov 1995).

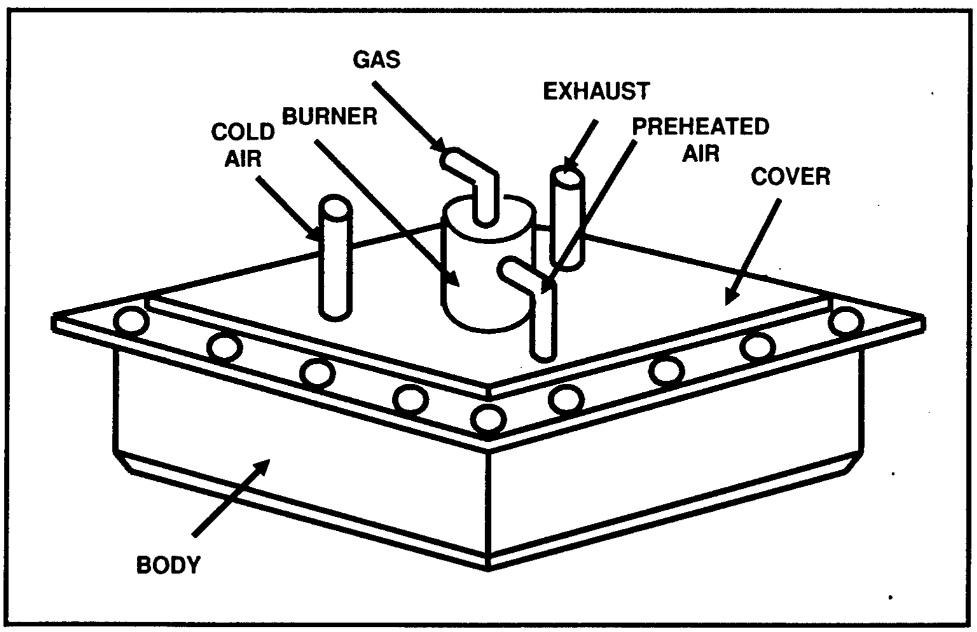

Figure 7. Flat plate heater.

Medical Waste Treatment System

The conventional technologies for treating medical waste are incineration and steam sterilization (also referred to as *autoclaving*). During the last decade, various alternative technologies have been developed and successfully deployed in the marketplace. Some of these are combinations of two or more treatment steps (e.g., shredding, compaction, steam sterilization, chemical disinfection, dry heat sterilization, microwave disinfection, electrothermal deactivation, etc.). Autoclaving can be either stationery or rotating, the latter being the state-of-the-art technology. Major manufacturers and providers of medical waste treatment systems include Baker, SantaPak, Tempico, and Waste Management.

Mineral Wool Melter

Mineral wool is produced by melting basalt and blast furnace slag in coke-fired cupolas. Environmental concerns over high-temperature furnaces, especially coke-fired units, are leading to the development and use of electric melters. To help industry avoid the cost of switching to electric melters, the Institute of Gas Technology (IGT) has licensed an innovative technology for producing mineral melts from its commercial development partner, the Gas Institute of the Academy of Science of the Ukraine. This advanced natural gas technology features direct firing of natural gas and oxidant (preheated air, enriched air, or oxygen) into and under the surface of the bath of mineral wool to be melted. Combustion products bubbling through the bath provide very effective heat transfer, reduce the overall temperature of the gases, and consequently, the NOx emission levels. Furthermore, the bubbles increase bath turbulence and, thereby, promote melt composition homogeneity. Finally, any carbon or organic material in the feed is used, enhancing thermal efficiency.

Oscillating Combustion Technology

Oscillating combustion is a retrofit NOx reduction technology for the high-temperature, natural gas-fired furnaces. It involves the creation of successive, NOx formation-retarding, fuel-rich and fuel-lean zones within the furnace, resulting in a forced oscillation of the fuel flow rate. When oxygen is used, its flow rate may be oscillated out-of-phase with the fuel to remove heat from the zones before they mix, reduce the overall peak flame temperature, and thus, NOx formation. Heat transfer from the flame to the load – and therefore furnace productivity – may also increase due to the existence of more luminous, fuel-rich zones and the breakup of the thermal boundary layer. CeramPhysics is adapting its solid-state valve for this application. Experiments conducted to date show a

promising future for implementation of this novel concept in real-world applications.

Oxygen-Enriched Air Staging (OEAS) System for Regenerative Glass Furnaces

OEAS is the most advanced retrofit NOx control process of its kind for regenerative glass furnaces. It reduces these emissions by 30 to 60 percent; retrofits easily with no effect on furnace performance or glass quality; is the lowest-cost option for substantially reducing NOx; is now commercially available for endport regenerative glass melting furnaces; and has a unique method of air staging that shows potential for beneficial application to other high-temperature processes. Table 7 lists NOx reduction technologies in terms of their percent NOx reduction potential, the increase in cost per ton of glass produced, and the corresponding abatement cost per ton of NOx reduction. The OEAS technology exemplifies the lowest capital and operating cost option.

Table 7. Comparison of NOx reduction technologies.

Technology*	NOx Reduction(%)	Cost Increase ($/Ton Glass)	Cost($/T on NOx)
Cullet preheating	5	1.0	5,000
Electric Boosting	30	8.5	7,100
Selective Non-Catalytic Reduction	30	4.5	3,700
Oxygen-Enriched Air Staging (OEAS)	60	1.0	400
Selective Catalytic Reduction	75	9.0	3,000
Reburning (Pinkington 3R Process)	80	1.7	500
Oxy-Fuel Firing	80	10.5	3,200

*Source: Abbasi (1995).

4 Natural Gas Technology Screening Criteria Summary

At the end of 1995, a total of 725 DOD installations were located within the continental United States and Alaska. Of these, 27 percent were in the Army or National Guard, 45 percent were in the Navy or Marines, 25 percent were in the Air Force or Air National Guard, and the remaining 3 percent were in the Defense Logistics Agency or DOD facilities in Washington, DC. If one were to consider only large installations, about 300 DOD facilities are almost equally divided among the Army, the Navy, and the Air Force. It is further estimated that 76 percent of the DOD installations use natural gas and 74 percent use heating fuels (*DEIS* 1990). The facility planner (and/or engineer), therefore, is more likely to adopt advanced natural gas technologies at his/her site.

No two military installations are alike. Each DOD facility will be unique in terms of its location, combination of residential, commercial, and industrial building, magnitude and characteristics of energy use, availability of alternate fuels, presence/absence of a local distribution company (LDC) in the area, permanent/temporary nature of the military installation, etc. Therefore, it is not feasible to define a generic set of gas technology screening criteria for what otherwise could be termed a “typical” facility. The collection and compilation of such data from all DOD facilities is beyond the scope of this project.

The facility planner (and engineer) responsible for the planning, implementation, operation, and maintenance of various energy utilization technologies at a given military installation, therefore, must address a number of installation-related parameters and several other economic and infrastructure issues prior to evaluating the potential impact of implementing any advanced gas utilization technology at his/her site. These screening criteria – most of which are independent of a specific technology being evaluated or considered for implementation – can generally be divided into two categories: (1) go/no-go decision criteria, and (2) other installation-related parameters and economic/infrastructure issues that need to be considered (and, if possible, quantified).

Go/No-Go Decision Criteria

The following go/no-go decision criteria, listed alphabetically to avoid any implied order of priority, will help facility planners determine whether or not they should proceed with an examination of other military installation-related parameters and an analysis of economic/infrastructure issues as they prepare to evaluate and/or implement specific advanced gas utilization technologies at a given DOD facility:

- *Availability of Natural Gas.* If natural gas is not available at a given DOD installation, then the cost of bringing it to the facility may far outweigh any benefits to be derived from implementing natural gas utilization technologies. Furthermore, many DOD installations cover large areas. In such cases, natural gas may be available at one corner of the facility but not at or around the potential application site, thereby, increasing the cost of implementing a particular gas utilization technology at that location.

- *Compatibility with Existing Facilities.* Implementation of advanced natural gas utilization technologies should cause minimal disruptions, if any, to existing infrastructure such as distribution piping, air duct system, water/sewer network, etc.

- *Intangible Parameters.* The facility engineer must also address all applicable intangible parameters such as social/political considerations and any others that might have been specified at higher levels within the DOD.

- *Nature of DOD Facility.* If, for example, a given DOD facility is an ammunition plant/depot, it may not be suitable for implementation of gas utilization technologies with open flames. Alternatively, a DOD facility in consideration may have been designated either a "historic" or "archeological" site, and may not allow implementation of gas technologies.

Other Installation-Related Parameters and Economic/Infrastructure Issues

Installation-Related Parameters

The following installation-related parameters need to be considered and, if possible, quantified for a given DOD facility for a more meaningful evaluation and effective implementation of advanced gas utilization technologies:

- *Daily and Seasonal Load Profile.* This basic data is needed for estimating the potential number of units of a given set of natural gas utilization technologies that can be implemented at the facility. One can start with the population database, an inventory of gas using equipment, fuel use characteristics of individual appliances, weather data, typical daily and seasonal load profiles for different classes of users, etc.

- *Operating Pressure Range.* Whether the amount of pressure needed for proper operation of a given gas utilization technology at a particular site is available will depend on the characteristics of the natural gas distribution system in place. A low pressure system, for example, operates at pressures that are in the range of 3 to 8 oz./sq in.,* and seldom exceed 1.5 pounds per square inch (psi). Medium pressure distribution systems operate at a pressure of from 1.5 to 50 psi. To avoid excessive leakage, design pressure normally should not exceed 25 psi. It is estimated that no DOD installation will have a gas distribution system operating at pressures above 50 psi.

- *Peak-to-Base Load Ratio.* The daily and seasonal load profiles can be used to derive base and peak load requirements (and, therefore, the peak-to-base load ratio) at a given DOD installation over a specified period. This data will help in the proper selection of technologies that are best suited for specific base and peak load requirements.

- *Piping System Layout and Configuration.* DOD installations operating at low pressures are required to be well looped with adequately sized piping. Specific system layout and configuration at a given DOD facility will, therefore, dictate the selection of certain gas utilization technologies. For example, implementation of technologies suitable for large loads (such as hospitals and laundry boiler plants) will require gas connection directly from feeder lines.

- *Subsystem Isolation.* Depending on the site characteristics and criticality of an individual building to the overall operation of that military installation, implementation of a given gas utilization technology may be governed by the existence and/or the specific design/configuration of gas distribution subsystem isolation at that location.

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* 1 oz = 28.34g; 1 sq in. = 6.45 cm^2; 1 psi = 6.89 kPa.

Economic and Infrastructure Issues

Even after passing through all of the go/no-go decision criteria listed above and ascertaining technical feasibility of implementing a given gas utilization technology at a specific DOD site, the facility planner still must address several other issues related to economic viability, regulatory compliance, human resource requirements, etc. These issues include, but are not necessarily limited to, the following:

- *Cost of Natural Gas and Alternative Fuels.* It is envisioned that for most DOD facilities the source of natural gas will be either a Local Distribution Company (LDC) or a gas transmission company in the region. Alternate fuels may include heating oil, electricity, and propane-air. LNG may be an option for those facilities near an LNG supply and not currently connected to the natural gas distribution system. Many DOD facilities enjoy special discount rates for various energy sources from local utilities and alternative fuel providers. The relative cost of natural gas as a fuel source must be reasonable for economic viability of adopting advanced natural gas utilization technologies at a given DOD installation.

- *Operation and Maintenance Skills.* Implementation of a particular advanced gas utilization technology may call for on-site availability of personnel skilled and/or trained in handling all aspects of its operation and maintenance.

- *Regulatory Requirements.* While a DOD installation is considered a Federal facility, it may be subjected to local and regional safety and environmental codes and regulations as far as the installation and maintenance of gas utilization technologies is concerned. All Federal regulations and requirements as promulgated by the Army, the Navy, and/or the Air Force will, of course, apply to these military installations as well.

- *Reliability of Fuel Supply.* Because of their nature and criticality to the security of the nation, it is necessary that the gas supply be very reliable with minimum potential for interruptions. The extent to which this degree of reliability is specified for a given DOD facility will depend on the strategic location and importance of that military installation.

5 Energy Conservation Opportunities (ECO) Description

ECO Identification Numbers

This section of the report describes 38 individual natural gas-fired energy conservation opportunities (ECOs) that have been identified as potential candidates for incorporation in the revised version of the REEP program. For each ECO, a brief background on potential application(s) of a given ECO is followed by a listing of its relevant technical and economic performance parameters, and a short note on evaluation algorithm. To facilitate discussion of individual ECOs – and to avoid repetition of certain topics that span several similar ECOs – each ECO is assigned a unique identification number (see Table 8), and all applicable ECO numbers are duly noted when a particular point of discussion pertains to two or more ECOs.

Common Topics

The majority of ECO algorithms are suitable for first-pass evaluation of the various natural gas technologies. At an installation level, however, more detailed or different types of data/information will generally be required to properly evaluate a particular technology. As mentioned in the preceding chapter, local conditions and circumstances at a given DOD facility can have a significant influence on whether a particular gas utilization technology will yield an acceptable payback or return on investment. Furthermore, there are a few common topics that need to be addressed before individual ECO descriptions are presented. These topics include notation conventions, cooling season-related data in the current version of the REEP program, energy consumption computation techniques, and importance of part-load performance.

Table 8. Listing of advanced natural gas ECOs.

ECO Category	Advanced Natural Gas Technology	ECO No.
Family Housing HVAC Systems	Desiccant Cooling - Dehumidification System (< 5 RT,)	F01
	Desiccant Cooling - Sensible and Latent Cooling (< 5 RT)	F02
	Gas-Engine-Driven Heat Pump	F03
	High-Efficiency Gas Furnace, Recuperative	F04
	High-Efficiency Gas Furnace, Condensing	F05
	High-Efficiency Gas Furnace, Pulse Combustion	F06
Building HVAC Systems	Desiccant Cooling - Dehumidification System (5 to 25 RT)	B01
	Desiccant Cooling - Dehumidification System (25 to 100 RT)	B02
	Desiccant Cooling - Dehumidification System (> 100 RT)	B03
	Desiccant Cooling - Sensible and Latent Cooling (5 to 25 RT)	B04
	Desiccant Cooling - Sensible and Latent Cooling (25 to 100 RT)	B05
	Desiccant Enthalpy Recovery Wheel (5 to 25 RT)	B06
	Infrared Radiant Heating System	B07
Utilities and Heating/Cooling Plants	Cogeneration - Gas Turbine (< 5 MW)	U01
	Cogeneration - Gas Turbine (5 to 20 MW)	U02
	Cogeneration - Phosphoric Acid Fuel Cell	U03
	Cogeneration - Reciprocating Engine (< 100 kW)	U04
	Cogeneration - Reciprocating Engine (100 to 500 kW)	U05
	Cogeneration - Reciprocating Engine (500 kW to 2 MW)	U06
	Cogeneration - Reciprocating Engine (> 2 MW)	U07
	Direct-Fired Gas Absorption Chiller (< 5 RT)	U08
	Direct-Fired Gas Absorption Chiller (5 to 25 Tons)	U09
	Direct-Fired Gas Absorption Chiller (25 to 100 Tons)	U10
	Direct-Fired Gas Absorption Chiller (>100 Tons)	U11
	Gas Engine-Driven Air Compressor	U12
	Gas Engine-Driven Chiller (5 to 25 Tons)	U13
	Gas Engine-Driven Chiller (25 to 100 Tons)	U14
	Gas Engine-Driven Chiller (>100 Tons)	U15
	High-Efficiency Gas Boiler (< 100 hp)	U16
	High-Efficiency Gas Boiler (100 to 250 hp)	U17
	High-Efficiency Gas Boiler (> 250 hp)	U18
Industrial/Process Applications	Composite Radiant Tube	I01
	Fuel Based Nitrogen Generator	I02
	Low-Inertia Heat-Treating Furnace (Flat Plate Heater)*	I03
	Medical Waste Treatment System	I04
	Mineral Wool Melter*	I05
	Oscillating Combustion Technology*	I06
	Oxygen-Enriched Air Staging System for Regen. Glass Furnaces	I07

* Emerging technologies - Not yet commercially available

Notation Conventions

To facilitate better understanding of the discussion presented in the remainder of this chapter, the following conventions are used:

- ECO algorithm variable names are shown in the following typeface: variable.
- ECO assumptions are represented by A_X where X is the number of the assumption.

- In cases where suggested modifications in ECO evaluation algorithms are extensive, applicable relationships are presented in a traditional mathematical equation format.
- Minor ECO evaluation algorithm modifications are presented in the "programming" format—i.e., as they appear in the *ECOname*.prg file.

In the course of our review of evaluation algorithms for those currently in the REEP program – and in case of new ECOs that are suggested for incorporation in the revised version of the REEP program – we have identified the need for modifying a number of existing assumptions and creating several new ones. The following conventions are used to report on these items:

- New (previously nonexistent) assumptions are shown in *italics*.
- Changed assumptions are shown in **boldface**.
- Assumptions that "may" need modification are shown underlined. These are the assumptions which, due to the nature of the suggested modifications in the ECO evaluation algorithm, are likely to change. However, not enough information was available in the REEP documentation to recommend specific values for these assumptions.

Cooling Season-Related Data in REEP

There are several installation data elements in the current version of the REEP program that are used to calculate full load heating and/or cooling hours and, subsequently, heating and/or cooling seasonal energy needs. For the cooling season, these include cooling degree days, cooling season days, summer design temperature, and full load cooling hours. Full load cooling hours are calculated from cooling degree days and interior and exterior design temperatures.

During the review of various ECO algorithms, it was found that some of the cooling season related installation data elements show inconsistencies when compared to others for the same installation. For example: in the program desicool.prg, used for desiccant dehumidification ECOs, cooling degree days is used to calculate the average dry-bulb temperature during the cooling season. An examination of the calculated values for some installations indicates that the values may be erroneously high. Similarly, full load cooling hours values are likely overstated for many installations. For a detailed discussion of the inconsistencies, refer to Appendix B, "Discussion On Cooling Season-Related Data in REEP."

Energy Consumption Computation Techniques

A review of existing ECO algorithms in REEP that pertain to the screening/ evaluation of various gas-fired cooling reveal that, in general, the approximate approach employed in REEP is sufficient to make a go/no-go decision for generic (or a group of similar) technologies. However, if one were to undertake an in-depth, site-specific evaluation to make estimates of energy and cost savings of implementing a given gas-fired cooling technology at a particular DOD installation, then it would be imperative that one of the following energy consumption computation techniques be employed.

Comparison of energy consumption for gas and electric cooling systems in a particular application can be carried out at various levels of sophistication. One of the simplest methods would be to multiply the rating point EER (Energy Efficiency Ratio), or rated gas and electric use, by an "estimated" equivalent number of full-load operating hours on the system over a cooling/heating season. Another simple method would be to multiply the SEER (Seasonal Energy Efficiency Ratio), IPLV (Integrated Part Load Value), SCOP (Seasonal Cooling Coefficient of Performance), or other seasonal measure of performance by an estimated number of "on" (or operating) hours of the system over a cooling season. Methodology for calculating IPLV performance is clearly defined in ARI Standard 340/360-93, entitled "Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment" (ARI Standard 340/360-93).

On the other end of the analytical spectrum are the sophisticated methods that use time-based temperature averaging to model the building's energy use. Most commonly used approaches are:

- *The hourly energy simulation methods* - which use transfer functions or lumped capacitance network method to account for thermal mass effects. To various extents, interactions between building loads and system controls are considered.
- *The monthly methods* - which use climate norms like minimum, maximum, or average monthly temperatures or degree-days; wind speed; and/or solar radiation to calculate hourly/daily/monthly/seasonal/annual loads and energy use.
- *The correlation interpolation methods* - which use regression analysis of thousands of detailed hourly simulations around the United States, and various building prototypes and energy conservation options.
- Still other types of analysis programs use *temperature-based annual bin method* to model the building's energy use.

There are arguments both for and against any of the above approaches as to their usefulness. The bin methods usually do not account for thermal mass effect. However, they are a good compromise between the higher cost of sophistication of the above mentioned approaches and the lower accuracy of simplified calculations.

In the bin-oriented approach, the gas and/or electric use of a given gas-fired cooling technology, as well as the building cooling load, are estimated as functions of the outdoor temperature. Combining that performance with the local climatic data (i.e., the number of climatic hours in each temperature bin) produces a seasonal performance measure for the system, in that climate. By multiplying the seasonal gas and electric consumption by a factor indicating the duty cycle for the system (i.e., whether the unit is "on" 24 hours/day or some lesser amount) one can then estimate seasonal fuel and electric usage.

It is suggested that the bin method be employed for an in-depth, site-specific evaluation of gas-fired cooling products to compute the seasonal loads, and the U.S. Department of Energy (DOE) climate regions be adopted to describe the local areas of interest. Each DOE region has been defined in terms of number of annual hours spent in each 5 °F bin temperature range. To compute the seasonal cooling load for a building type, for a 24 hour/day application, one merely multiplies the number of climate hours, in each 5 °F bin, by the cooling load required in the same bin. To account for buildings which are not air-conditioned on a 24 hour/day basis, it is proposed that the seasonal 24 hour/day load be multiplied by a "seasonal load adjusting factor," between 0 and 1, which indicates the average seasonal fractional usage of the air-conditioning equipment in the application under study. For example, if a commercial building type is assumed to be normally occupied (and air conditioned) for 16 hours/day, the 24 hours/day seasonal load adjusting factor would be 0.6667 (i.e., 16/24).

Importance of Part-Load Performance

Since the REEP program basically is a screening tool, it is not critical that the current version of the REEP program is devoid of considerations for part-load performance. This, however, may penalize the gas-fired cooling technologies being screened, sometimes severely, as the system efficiency (COP, EER) changes at part-load conditions. Unfortunately, the influence of part-load performance on seasonal evaluation is not uniform for the equipment types and installations and, therefore, cannot be covered (or estimated) by simple factors (or proxies) in a screening tool such as REEP.

For the part-load performance of chillers, which have typical performances defined in terms of the temperature of the inlet water to the condenser, a link must be established between that condenser water and the outdoor temperature. To provide that link, we recommend that the REEP program use the ARI Standard 550-92. In that Standard, it is assumed for part-load performance estimation, that the temperature of the condenser inlet water, returning to the unit from the cooling tower, is 85 °F at the rating point of the equipment (which we have assumed to be 95 °F outdoor), and reduces at the rate of 2.5 °F per 10 percent load reduction. This allows one to correlate "load versus outdoor temperature" to "load versus inlet condenser water temperature," and permits the seasonal performance computation methodology for chillers to follow directly the methodology for the other types of air-conditioning equipment.

For the part-load performance of desiccant-based cooling systems, which use outdoor air for reactivation, the use of coincident relationship between outdoor wet and dry bulb temperatures, which should be determined for all climatic regions, is recommended.

Individual ECO Descriptions

Family Housing HVAC Systems (ECO Nos. F01 through F06)

The following six ECOs are covered under this category:

F01. Desiccant Cooling - Dehumidification System (< 5 RT)

F02. Desiccant Cooling - Sensible and Latent Cooling (< 5 RT)

F03. Gas Engine-Driven Heat Pump

F04. High-Efficiency Gas Furnace, Recuperative

F05. High-Efficiency Gas Furnace, Condensing

F06. High-Efficiency Gas Furnace, Pulse Combustion.

F01. Desiccant Cooling - Dehumidification System (< 5 RT)

Background. A desiccant cooling system removes large amounts of moisture from incoming air before it reaches the cooling coil, thereby reducing the latent load on the system, and hence saving energy. The air is first passed through a desiccant wheel, which removes moisture and lowers the relative humidity. The desiccant wheel is regenerated using gas or waste heat. As the moisture is removed, the air temperature increases. It must be subsequently cooled by a

sensible heat exchanger (wheel) which, in turn, is cooled by (for example) building exhaust air. The desiccant wheel can be regenerated using waste heat from a nearby boiler or gas engine. (However, this is not taken into account in this analysis.)

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p. 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	COMFORT ENTERPRIZES Co.
Type/Brand Name	The Comfort Solution™
Unit Capacity	**165 [cfm]**
Installed Cost	**2,000 [$]**
Economic Life	**15 [years]**
Unit Elect. Consumption	**0.086 [kW]**
Unit Gas Consumption	**None (indirect heat supplied from gas water heater)**
Recurring Cost	**2 [% of Capital Cost/year]**
Demand Diversity Factor	0.8
Chiller COP	3
Discount Quantity	5 [units]

Facility Assumptions. Latent load (dehumidification) on the building is taken care of by this system. First the average outdoor humidity ratio for each location summer season is calculated. Next, the enthalpy of the incoming air stream and the air stream leaving the desiccant wheel are calculated. This also assumes an average room control temperature of 75 °F and relative humidity of 45 percent with 20 percent make-up air in the air handling unit. Sensible cooling (the remaining load on the building), if needed to reach the 75 °F indoors, would be provided by combining the systems with engine-driven or absorption chillers or air conditioners.

Ventilation	12 [hrs/day]
Barracks (% Applicable)	33%
Training (% Applicable)	20%
R&D (% Applicable)	80%
Administration (% Applicable)	50%
Community (% Applicable)	50%
Medical (% Applicable)	100%
Locations (% Applicable)	100%

Algorithm Modifications. These systems use waste heat from hot water heaters; therefore no additional gas usage is incurred. The percent locations applicable assumption may need modification because these systems are linked to the presence of a hot water heater. Since it is suggested that multiple sizes of desiccant dehumidification ECOs be incorporated in the revised version of the

REEP program, the "percent locations applicable" assumption may have to be changed.

The first suggested algorithm change pertains to the way the variable numecouni (number of ECO units) is used in subsequent calculations of energy usage and savings. The second, yet more significant, suggested change in the evaluation algorithms for all desiccant dehumidification ECOs is ***not*** to assume that exit air stream conditions are at 75 °F and 45 percent relative humidity (the indoor conditions). Instead, specific relationships to calculate the temperature and relative humidity are recommended.

Units Calculation. Although the units calculation (numecouni) is used in subsequent calculations of energy usage and savings, the capacity of the desiccant dehumidifier (A_{11}, cfm/unit) is not accounted for in the units calculation. Also, the penetration factor adjustment (1-penfac) and percent locations applicable (A_{12}) are applied only to the final term of the units calculation (common facilities area). After examining other ECO algorithms, it is clear that the intent here is to apply these two adjustments to the total area, and not just to the common facilities area.

The following relationship should be used, which will account for changes in unit capacity as well as properly applying the penetration factor and locations applicable percentage. This relationship is based on an assumption that the existing units calculation is implicitly based on a unit capacity of 12000 cfm.

$$numecouni = \left(2\frac{A_2}{100}\frac{K_T}{22} + 3\frac{A_4}{100}\frac{K_R}{36} + \frac{A_3}{100}\frac{K_H}{16} + 1.25\frac{A_6}{100}\frac{K_A}{15} + 3\frac{A_1}{100}\frac{K_B}{45.6} + \frac{A_5}{100}\frac{K_C}{10.2}\right)(1 - penfac)A_{12}\frac{12000}{A_{11}}$$

where K_X are installation areas (Ksf) with the subscripts representing:

T Training (traare)

R Research, Development, and Testing (rdtare)

H Hospital and Medical (hosmedare)

A Administrative (admare)

B Barracks (barare)

C Common Facilities (comfacare).

Cooling Season Days Check. The check for cooseaday < 10 should occur after, or as a part of, the units calculation. It appears that the intent of this check is to "disable" the ECO calculations when this test is satisfied. Forcing the units to zero is likely a preferable way to achieve this.

Temperature and Relative Humidity Calculation. It is recommended that the following modified relationships among dry and wet bulb temperatures (T_{DB} and T_{WB}), annual dry bulb hours (H_{DB}), air stream enthalpies (h_{IN} and h_{OUT}), and humidity ratios (W_{IN} and W_{OUT}) be incorporated into the revised REEP program as far as evaluation algorithms for all desiccant dehumidification ECOs are concerned:

$$T_{WB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{WB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{WB_{85-89}} + 459.67$$

$$T_{DB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{DB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{DB_{85-89}} + 459.67$$

where the average dry-bulb temperature, $\overline{T}_{DB}$, for the temperature bins 80-84 and 85-90 should be 82.5 and 87.5 °F, respectively. This assumes that the temperature bin boundaries are (80,85) and (85,90).

Further, P_{WS} (water vapor saturation pressure) relationship needs to be in terms of T_{DB}, and not T_{WB}.

Next, the relationships for air humidity ratio and enthalpies should be defined as follows:

$$W = \frac{(1093 - 0.556(T_{WB} - 459.67))W_S - 0.24(T_{DB} - T_{WB}))}{1093 + 0.444(T_{DB} - 459.67) - (T_{WB} - 459.67)},$$

$$h_{IN} = 0.24(T_{DB} - 459.67)W(1061 + 0.444(T_{DB} - 459.67)), and,$$

$$h_{OUT} = 0.24T_{DB_{OUT}} + W_{OUT}(1061 + 0.444T_{DB_{OUT}})$$

where:

$T_{DB_{OUT}}$ = T_{DB} for liquid desiccant systems with cooling tower

= $0.84551W + 0.8375T_{DB} + 46.768$ for solid desiccant rotary wheel systems

and

W_{OUT} = 0.45W for liquid desiccant systems with cooling tower

= $0.708105W + 0.066072T_{DB} - 8.02371$ for solid desiccant rotary wheel systems

F02. Desiccant Cooling - Sensible and Latent Cooling (< 5 RT)

Background. A desiccant cooling system removes large amounts of moisture from incoming air before it reaches the cooling coil, thereby reducing the latent load on the system, and hence saving energy. The air is first passed through a desiccant wheel that removes moisture and lowers the relative humidity. The desiccant wheel is regenerated using gas or waste heat. As the moisture is removed, the air temperature increases. It must be subsequently cooled by a sensible heat exchanger (wheel) which, in turn, is cooled by (for example) building exhaust air. The desiccant wheel can be regenerated using waste heat from a nearby boiler or gas engine. (However, this is not taken into account in this analysis.)

The selected ECO offers all the benefits of natural gas-fired desiccant cooling in a compact, energy-efficient package. Its 30 percent fresh-air makeup provides more than enough ventilation capacity to serve as a standalone air conditioning system that meets both current and proposed IAQ guidelines. Further, when coupled with an energy recovery wheel, the selected system can be used as an energy-efficient, 100 percent outdoor air package. It represents a new approach to desiccant cooling for residential and light commercial applications. It offers low parasitic electrical requirements and low operating costs.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	LAROCHE AIR SYSTEMS Inc.
Type/Brand Name	NovelAire™
Unit Capacity	**1,000 [cfm]**
Installed Cost	**10,000 [$]**
Economic Life	**15 [years]**
Unit Elect. Consumption	**1.0 [kW]**
Unit Gas Consumption	**0.04 [MBtu/hour]**
Recurring Cost	1 [% of Capital Cost/year]
Demand Diversity Factor	0.8
Chiller COP	3
Discount Quantity	5 [units]

Facility Assumptions. All facility assumptions, except air delivery conditions, remain the same for this ECO.

Locations (% Applicable) 100%

Air Delivery Conditions 55°F D.B. / 53°F W.B.

Algorithm Modifications. Since it is suggested that multiple sizes of desiccant cooling ECOs be included in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

The first suggested algorithm change pertains to the way the variable numecouni (number of ECO units) is used. The second, yet more significant, suggested change in the evaluation algorithms for all desiccant cooling ECOs is not to assume that exit air stream conditions are at 75 °F and 45 percent relative humidity (the indoor conditions). Instead, specific relationships to calculate the temperature and relative humidity are recommended. The last, but not the least, suggested change deals with the calculations of energy consumed (or saved).

Units Calculation. The capacity of the enthalpy wheel (cfm/unit) is presented in the REEP manual, but is not accounted for in the ECO algorithm, nor is it used in the units calculation. Also, the penetration factor adjustment (1-penfac) and percent locations applicable (A_{12}) are applied only to the final term of the units calculation (common facilities area). After examining other ECO algorithms, it is clear that the intent here is to apply these two adjustments to the total area, and not just to the common facilities area.

The following relationship should be used, which will account for changes in unit capacity as well as properly applying the penetration factor and locations applicable percentage. A_{13} would be a new assumption representing the unit capacity (cfm/unit).

$$\text{numecouni} = \left(2\frac{A_2}{100}\frac{K_T}{22} + 3\frac{A_4}{100}\frac{K_R}{36} + \frac{A_3}{100}\frac{K_H}{16} + 1.25\frac{A_6}{100}\frac{K_A}{15} + 3\frac{A_1}{100}\frac{K_B}{45.6} + \frac{A_5}{100}\frac{K_C}{10.2} \right)(1 - \text{penfac})A_{12}\frac{1500}{A_{13}}$$

where K_X are installation areas (Ksf) with the subscripts representing:

T Training (traare)

R Research, Development, and Testing (rdtare)

H Hospital and Medical (hosmedare)

A Administrative (admare)

B Barracks (barare) and

C Common Facilities (comfacare).

The units calculation is not used in subsequent calculations of heating or cooling energy saved. Rather, these savings are based on the assumed ventilation rate (A11, cfm/ksf).

Temperature and Relative Humidity Calculation. It is recommended that the following modified relationships among dry and wet bulb temperatures (T_{DB} and T_{WB}), annual dry bulb hours (H_{DB}), air stream enthalpies (h_{IN} and h_{OUT}), and humidity ratios (W_{IN} and W_{OUT}) be incorporated into the revised REEP program as far as evaluation algorithms for all desiccant sensible and latent cooling and enthalpy recovery wheel ECOs are concerned:

$$T_{WB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{WB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{WB_{85-89}} + 459.67$$

$$T_{DB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{DB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{DB_{85-89}} + 459.67$$

where:

H_{DBx} = the annual dry bulb hours in the X temperature range bi $\overline{T}_{WB_X}$

and

$\overline{T}_{DB_X}$ = the mean coincident wet and dry, respectively, bulb temperatures in the X temperature range bin.

The average dry-bulb temperature, $\overline{T}_{DB}$, for the temperature bins 80-84 and 85-90 should be 82.5 °F and 87.5 °F, respectively. This assumes that the temperature bin boundaries are (80,85) and (85,90).

Further, P_{WS} (water vapor saturation pressure) relationship needs to be in terms of T_{DB}, and not T_{WB}.

Next, the relationship for air humidity ratio should be defined as:

$$W = \frac{\left(1093 - 0.556(T_{WB} - 459.67)W_S - 0.24(T_{DB} - T_{WB})\right)}{1093 + 0.444(T_{DB} - 459.67) - (T_{WB} - 459.67)}$$

Energy Calculation. The remaining modified relationships pertain to the determination of unit demand, and energy usage and savings. Unit demand has been adjusted to represent the demand per unit, which can now vary with its capacity (cfm/unit):

$$\text{Udem} = A_{11} \times 60 \times 0.075 \times \Delta H \frac{A_{13}}{1500}$$

where:

A_{11} = assumption 11 (ventilation rate)

A_{13} = assumption 13 (unit capacity, cfm

ΔH = Change in enthalpy which, in turn, is given by the following equation:

$$\Delta H = 0.24\left(T_O - T_{EC}\right) + 1061\left(W - W_{EC}\right) + 0.444\left(WT_O - W_{EC}T_{EC}\right),$$

where:

T_O = T_{DB} converted to °F

T_{EC} = the indoor air exhaust temperature during cooling season (75 °F)

W_{EC} = the indoor air humidity ratio.

W_{EC}, in turn, must be calculated from the exhaust air conditions as follows:

$$W_{EC} = 0.62198 \frac{P_{W_{EC}}}{P_{AMB} - P_{W_{EC}}}$$

where:

$$P_{W_{EC}} = \frac{RH_{EC}}{100} P_{WS_{EC}}$$

$P_{WS_{EC}}$ represents the indoor air water saturation pressure, and is calculated using P_{WS} relationship but with T_{EC} in °R, and not in °F.

Heating energy saved is modified to more accurately determine the "degree-days" needed for the calculation:

$$\text{Heating Energy Saved} = \eta_s \dot{H}_{SENS}\left(T_{EH}D_H - \left(65D_H - HDD\right)\right) \times KSF_{NET}$$

where:

η_s = the efficiency of sensible heat recovery (assumption 9)

T_{EH} = the indoor air exhaust temperature during heating season (68 °F)

D_H = the heading season days

KSF_{NET} = the weighted sum of the space to be conditioned (per current REEP version)

Cooling energy saved is modified to reflect the changes in the Udem calculation:

$$\text{Cooling Energy Saved} = \eta_h \times \text{Udem} \times H_{DB>80} \times KSF_{NET} \frac{1500}{A_{13} 10^6}$$

where:

η_h = the efficiency of enthalpy recovery

$H_{DB>80}$ = the Summer A/C Criteria Dry Bulb Hours > 80 °F (per sacdbh)

KSF_{NET} = the weighted sum of the space to be conditioned (per current REEP version)

Summer demand saved is calculated from cooling energy saved, as is the case in several other ECO algorithms:

$$SummerDemandSaved = \frac{CoolingEnergySaved}{H_{DB>80} A_7} \frac{10^6}{3412}$$

where the final term above contains the element 3412 Btu/kWh.

To further improve the screening/evaluation of desiccant cooling systems, it is suggested that the first-order approximation of part-load performance be taken into consideration. This can be achieved by supplementing the modified screening/evaluation algorithm for the desiccant dehumidification ECOs (ECO Nos. F01 and B01 through B03) with the improved thermal efficiencies of a sensible heat exchanger (usually in the range of 85 to 92 percent) and evaporation pads (degree of humidification of both streams).

Sources *Natural Gas Cooling Equipment Guide*, 4th ed., April 1996; American Gas Cooling Center, 1515 Wilson Blvd., Arlington, VA 22209.

F03. Gas Engine-Driven Heat Pump

Background. A gas engine-driven heat pump uses the same cooling process as a conventional electric-powered system except the electric motor is replaced by a gas engine. The engine provides variable-speed operation, higher part-load efficiency, and waste-heat recovery. Switching to natural gas from electricity can

reduce summer peak electrical demand, and provide a summer gas load that may bring financial incentives from the local natural gas utility. This analysis does not consider the benefits of waste-heat recovery for domestic hot water use or steam generation. However, during the heating season, it considers the very effective heating function this system provides. At present, only one type of gas engine-driven heat pump is available on the market that fits into the HVAC category of <5 RT size range.

Family housing uses a significant amount of the Army's heating/cooling energy. Heat pumps provide efficient cooling in the summer months and can meet most of the heating load during the winter months. The gas engine heat pumps replace both the furnace and the air conditioning units. Since it does replace both pieces of HVAC equipment, the gas engine-driven heat pump is applied only to installations that meet the Army's air conditioning criteria. Although the ECO does not address these capabilities, the gas engine heat pump can heat water for domestic use and it can also act as backup generator during electrical outages if it would be modified to provide such service.

This technology is relatively new. In the near future, the unit may be upgraded for light commercial applications. Currently, it represents the best energy conserving products while offering the best comfort management on the market.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above for further explanation of numbers shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	York International Corporation	
Type/Brand Name	Triathlon™	
Size of Replacement Unit	3.5*	RT
SEER of Old AC Unit	8	
AC Unit Wattage	3.26	kW
Gas Usage	9,231	Btu/RT
Cooling Temperature/Delivered Air Temp.	78/50	°F
Gas Chiller Electrical Usage	0.2	kW/RT
Replaced Chiller Electrical Usage	1.25	kW/RT
Installed Cost per Unit	**7,800**	**$**
Increased Water Usage	none	
Penetration Factor	20	%
Recurring Costs	**180**	**$/year (or 4,000 hours of operation)**
CFCs Avoided	0**	lbs/RT
Discount Quantity	10	units
Heating Capacity	**94,000**	**Btu/hr**
Gas Usage	75,000	Btu/hr
Economic Life	10	years (or 40,000 hours of operation)

Family Housing Area Served per Unit	1.5	KSF
Efficiency of Old Furnace	65	%
Heat Pump Cooling COP	**1.30**	
Heat Pump Heating COP	**1.25**	
Heating Efficiency of Heat Pump	**125**	%

* The same unit is offered also in 3 RT capacity with the heating capacity/gas usage of 64,000/51,000 Btu/hr., respectively.

** The original, except for small-size window units, and engine-driven units use HCFC.

Facility Assumptions. This ECO was applied to family housing areas and it directly replaces the existing air conditioning unit and furnace with a gas engine-driven heat pump. The gas-fired heat pump algorithm bases energy savings on the difference in energy consumption between the old and the new unit, multiplied by the number of hours the unit would run annually. The number of hours an air conditioning system operates is a function of climate. The differences in the energy consumption are due to the high efficiency of the gas engine-driven heat pump.

The number of heat pumps replaced is calculated by dividing the installation's total cooling capacity in the respective range by an assumed heat pump size. Electrical savings and the gas cost increase are then determined based on the assumptions above. Economic benefit with respect to CFC replacement has not been calculated. The heat pump is assumed to be air-cooled.

Algorithm Modifications. For a detailed discussion of the recommended modifications for this ECO, see *Screening/Evaluation of Advanced Gas-Fired Cooling Technologies* section above. Specifically two changes – one minor and one rather significant – are recommended for this ECO algorithm. The calculation of cooling energy saved appeared as follows:

cooensav = xfulloacoo*numecouni*0.03

It appears as though 0.03 in the above equation is a "hard coding" of an ECO assumption and some conversion terms. It is suggested that this relationship be revised as follows:

cooensav = xfulloacoo*numecouni*xassum04v*12000/1000000

where:

xassum04v = assumption 4: A/C unit size (tons), and

12000/1000000 = the conversion from tons to millions of Btu

Also note that assumption 8 (Heat pump heating COP) is not used in the ECO algorithm. It appears to be a duplication of assumption 9 (heating efficiency of new equipment).

Sources "Direct contact with manufacturer," *Natural Gas Cooling Equipment Guide* 4th ed. April 1996, American Gas Cooling Center, 1514 Wilson Blvd., Arlington, VA 22209.

F04. High Efficiency Gas Furnace, Recuperative

Background. Family Housing uses a significant portion of the Army's heating energy. Replacement of existing low and medium efficiency furnaces with new high efficiency recuperative units represents significant potential for reduction in fuel usage and costs. Buildings best suited to conversion are those that currently have low and medium efficiency gas-fired furnaces. This technology is most suitable for family housing applications.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Seasonal efficiency of old plants	65	%
Seasonal efficiency of new plants	85	% (for recuperative, non-condensing unit)
Installed Cost	**1,700**	**$ (for recuperative, non-condensing unit)**
Recurring Cost / Year	**5**	**% of installed cost**
Economic Life	**15-20**	**years (depending on the heating load factor)**
Furnace Output	**100,000 Btu/hr**	
Discount Quantity	10	units
Family Housing Area Served per Unit	1.5	KSF
Electricity Conserved Delta Old/New	0.04	

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. For a given heating load, the gas energy saved for this ECO can be calculated as:

Gas energy saved = Current gas consumption x (1 - (Seasonal efficiency of old furnace / Seasonal efficiency of new furnace))

where:

Current gas consumption = Furnace output / Seasonal efficiency of old furnace.

The set of governing equations used in the current algorithm to calculate the operating benefits of high-efficiency gas furnaces for family housing is as follows:

Units = function of ksf per unit

heating energy saved = old furnace h / new furnace h) * heating degree-days per year * units * ksf per unit * 0.0165 MBtu per ksf per heating degree-day

electric energy saved = heating degree-days per year * electric consumption delta old vs. new * 0.003412 * units

F05. High Efficiency Gas Furnace, Condensing

Background. Family Housing uses a significant portion of the Army's heating energy. Replacement of existing low and medium efficiency furnaces with new high efficiency condensing units, but without pulse combustion represents significant potential for reduction in fuel usage and costs. Buildings best suited to conversion are those that currently have low and medium efficiency gas-fired furnaces. This technology is most suitable for family housing applications.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or <u>underlined</u>.)

Seasonal efficiency of old plants	65	%
Seasonal efficiency of new plants	**92**	**% (for condensing unit without pulse combustion)**
Installed Cost	**2,000**	**$ (for condensing unit without pulse combustion)**
Recurring Cost / Year	**5**	**% of installed cost**
Economic Life	**15-20**	**Years (depending on the heating load factor)**
Furnace Output	**100,000 Btu/hr**	
Discount Quantity	10	Units
Family Housing Area Served per Unit	1.5	KSF
Electricity Conserved Delta Old/New	0.04	

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. For a given heating load, the gas energy saved for this ECO can be calculated as:

Gas energy saved = Current gas consumption x (1 - (Seasonal efficiency of old furnace / Seasonal efficiency of new furnace))

where:

Current gas consumption = Furnace output / Seasonal efficiency of old furnace

The set of governing equations used in the current algorithm to calculate the operating benefits of high-efficiency gas furnaces for family housing is as follows:

units	=	function of ksf per unit
heating energy saved	=	(1 - old furnace h / new furnace h) * heating degree-days per year * units * ksf per unit * 0.0165 MBtu per ksf per heating degree-day
electric energy saved	=	heating degree-days per year * electric consumption delta old vs. New * 0.003412 * units

F06. High Efficiency Gas Furnace, Pulse Combustion

Background. Family Housing uses a significant portion of the Army's heating energy. Replacement of existing low and medium efficiency furnaces with new high efficiency pulse combustion units represents significant potential for reduction in fuel usage and costs. Buildings best suited to conversion are those that currently have low and medium efficiency gas-fired furnaces. This technology is most suitable for family housing.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Seasonal efficiency of old plants	65	%
Seasonal efficiency of new plants	**94**	**%**
Installed Cost	**2,200**	**$**
Recurring Cost / Year	**5**	**% of installed cost**
Economic Life	**15-20**	**Years (depending on the heating load factor)**
Furnace Output	**100,000 Btu/hr**	
Discount Quantity	10	units
Family Housing Area Served per Unit	1.5	KSF
Electricity Conserved Delta Old/New	0.04	

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. For a given heating load, the gas energy saved for this ECO can be calculated as:

Gas energy saved = Current gas consumption x (1 - (Seasonal efficiency of old furnace / Seasonal efficiency of new furnace))

where:

Current gas consumption = Furnace output / Seasonal efficiency of old furnace

The set of governing equations used in the current algorithm to calculate the operating benefits of high-efficiency gas furnaces for family housing is:

units	=	Function of ksf per unit
heating energy saved	=	(1 - old furnace h / new furnace h) * heating degree-days per year * units * ksf per unit * 0.0165 MBtu per ksf per heating degree-day
electric energy saved	=	Heating degree-days per year * electric consumption delta old vs. New * 0.003412 * units

Building HVAC Systems (ECO Nos. B01 through B07)

The following seven ECOs are covered under this category:

B01. Desiccant Cooling - Dehumidification System (5 to 25 RT)

B02. Desiccant Cooling - Dehumidification System (25 to 100 RT)

B03. Desiccant Cooling - Dehumidification System (> 100 RT)

B04. Desiccant Cooling - Sensible and Latent Cooling (5 to 25 RT)

B05. Desiccant Cooling - Sensible and Latent Cooling (25 to 100 RT)

B06. Desiccant Enthalpy Recovery Wheel (5 to 25 RT)

B07. Infrared Radiant Heating System.

B01. Desiccant Cooling - Dehumidification System (5 to 25 RT)

Background. A desiccant cooling system removes large amounts of moisture from incoming air before it reaches the cooling coil, thereby reducing the latent load on the system, and hence saving energy. The air is first passed through a desiccant wheel, which removes moisture and lowers the relative humidity. The desiccant wheel is regenerated using gas or waste heat. As the moisture is removed, the air temperature increases. It must be subsequently cooled by a sensible heat exchanger (wheel) which, in turn, is cooled by (for example) building exhaust air. The desiccant wheel can be regenerated using waste heat from a nearby boiler or gas engine. However, this is not taken into account in this analysis.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	Munters Corp.
Type/Brand Name	M-20 / DRYCOOL ®

Unit Capacity	**5,000 [cfm]**
Installed Cost	**35,000 [$]**
Economic Life	20 [years]
Unit Elect. Consumption	**1.5 [kW]**
Unit Gas Consumption	**0.404 [MBtu/hr]**
Recurring Cost	1 [% of Capital Cost/year]
Demand Diversity Factor	0.8
Chiller COP	3
Discount Quantity	5 [units]

Facility Assumptions. Latent load (dehumidification) on the building is taken care of by this system. First the average outdoor humidity ratio for each location summer season is calculated. Next, the enthalpy of the incoming air stream and the air stream leaving the desiccant wheel are calculated. This also assumes an average room control temperature of 75 °F and relative humidity of 45 percent with 20 percent make-up air in the air handling unit. Sensible cooling (the remaining load on the building), if needed to reach the 75 °F indoors, would be provided by combining the systems with engine-driven or absorption chillers or air conditioners.

Ventilation	12 [hrs/day]
Barracks (% Applicable)	33%
Training (% Applicable)	20%
R&D (% Applicable)	80%
Administration (% Applicable)	50%
Community (% Applicable)	50%
Medical (% Applicable)	100%
Locations (% Applicable)	100%

Algorithm Modifications. Since it is suggested that multiple sizes of desiccant dehumidification ECOs be incorporated in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

The first suggested algorithm change pertains to the way the variable numecouni (number of ECO units) is used in subsequent calculations of energy usage and savings. The second, yet more significant, suggested change in the evaluation algorithms for all desiccant dehumidification ECOs is not to assume that exit air stream conditions are at 75 °F and 45 percent relative humidity (the indoor conditions). Instead, specific relationships to calculate the temperature and relative humidity are recommended.

Units Calculation. Although the units calculation (numecouni) is used in subsequent calculations of energy usage and savings, the capacity of the

desiccant dehumidifier (A_{11}, cfm/unit) is not accounted for in the units calculation. Also, the penetration factor adjustment (1-penfac) and percent locations applicable (A_{12}) are applied only to the final term of the units calculation (common facilities area). After examining other ECO algorithms, it is clear that the intent here is to apply these two adjustments to the total area, and not just to the common facilities area.

The following relationship should be used, which will account for changes in unit capacity as well as properly applying the penetration factor and locations applicable percentage. This relationship is based on an assumption that the existing units calculation is implicitly based on a unit capacity of 12000 cfm:

$$\text{numecouni} = \left(2\frac{A_2}{100}\frac{K_T}{22} + 3\frac{A_4}{100}\frac{K_R}{36} + \frac{A_3}{100}\frac{K_H}{16} + 1.25\frac{A_6}{100}\frac{K_A}{15} + 3\frac{A_1}{100}\frac{K_B}{45.6} + \frac{A_5}{100}\frac{K_C}{10.2}\right)(1-\text{penfac})A_{12}\frac{12000}{A_{11}}$$

where K_X are installation areas (Ksf) with the subscripts representing:

T Training (traare)

R Research, Development, and Testing (rdtare)

H Hospital and Medical (hosmedare)

A Administrative (admare)

B Barracks (barare)

C Common Facilities (comfacare).

Cooling Season Days Check. The check for cooseaday < 10 should occur after, or as a part of, the units calculation. It appears that the intent of this check is to "disable" the ECO calculations when this test is satisfied. Forcing the units to zero is likely a preferable way to achieve this.

Temperature and Relative Humidity Calculation. It is recommended that the following modified relationships among dry and wet bulb temperatures (T_{DB} and T_{WB}), annual dry bulb hours (H_{DB}), air stream enthalpies (h_{IN} and h_{OUT}), and humidity ratios (W_{IN} and W_{OUT}) be incorporated into the revised REEP program as far as evaluation algorithms for all desiccant dehumidification ECOs are concerned:

$$T_{WB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{\overline{T}}_{WB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{\overline{T}}_{WB_{85-89}} + 459.67$$

$$T_{DB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{DB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{DB_{85-89}} + 459.67$$

where the average dry-bulb temperature, $\overline{T}_{DB}$, for the temperature bins 80-84 and 85-90 should be 82.5 and 87.5 °F, respectively. This assumes that the temperature bin boundaries are (80,85) and (85,90).

Further, P_{WS} (water vapor saturation pressure) relationship needs to be in terms of T_{DB}, and not T_{WB}.

Next, the relationships for air humidity ratio and enthalpies should be defined as follows:

$$W = \frac{\left(1093 - 0.556(T_{WB} - 459.67)W_S - 0.24(T_{DB} - T_{WB})\right)}{1093 + 0.444(T_{DB} - 459.67) - (T_{WB} - 459.67)},$$

$$h_{IN} = 0.24(T_{DB} - 459.67)\,W\left(1061 + 0.444(T_{DB} - 459.67)\right), \text{ and}$$

$$h_{OUT} = 0.24T_{DB_{OUT}} + W_{OUT}\left(1061 + 0.444T_{DB_{OUT}}\right)$$

where:

$T_{DB_{OUT}}$ = T_{DB} for liquid desiccant systems with cooling tower

= 0.84551W + 0.8375T_{DB} + 46.768 for solid desiccant rotary wheel systems

and

W_{OUT} = 0.45W for liquid desiccant systems with cooling tower

= 0.708105W + 0.066072T_{DB} - 8.02371 for solid desiccant rotary wheel systems.

B02. Desiccant Cooling - Dehumidification System (25 to 100 RT)

Background. A desiccant cooling system removes large amounts of moisture from incoming air before it reaches the cooling coil, thereby reducing the latent load on the system, and hence saving energy. The air is first passed through a desiccant wheel, which removes moisture and lowers the relative humidity. The desiccant wheel is regenerated using gas or waste heat. As the moisture is removed, the air temperature increases. It must be subsequently cooled by a

sensible heat exchanger (wheel) which, in turn, is cooled by (for example) building exhaust air. The desiccant wheel can be regenerated using waste heat from a nearby boiler or gas engine. However, this is not taken into account in this analysis.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above for further explanation of numbers, which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	ATS
Type/Brand Name	DES-12000-152-G/1
Unit Capacity	**12,000 [cfm]**
Installed Cost	**102,000 [$]**
Economic Life	20 [years]
Unit Elect. Consumption	**18.4 [kW]**
Unit Gas Consumption	**0.75 [MBtu/hr]**
Recurring Cost	1 [% of Capital Cost/year]
Demand Diversity Factor	0.8
Chiller COP	3
Discount Quantity	5 [units]

Facility Assumptions. Latent load (dehumidification) on the building is taken care of by this system. First the average outdoor humidity ratio for each location summer season is calculated. Next, the enthalpy of the incoming air stream and the air stream leaving the desiccant wheel are calculated. This also assumes an average room control temperature of 75 °F and relative humidity of 45 percent with 20 percent make-up air in the air handling unit. Sensible cooling (the remaining load on the building), if needed to reach the 75 °F indoors, would be provided by combining the systems with engine-driven or absorption chillers or air conditioners.

Ventilation	12 [hrs/day]
Barracks (% Applicable)	33%
Training (% Applicable)	20%
R&D (% Applicable)•	80%
Administration (% Applicable)•	50%
Community (% Applicable)	50%
Medical (% Applicable)	100%
Locations (% Applicable)	100%

Algorithm Modifications. Since it is suggested that multiple sizes of desiccant dehumidification ECOs be incorporated in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

The first suggested algorithm change pertains to the way the variable numecouni (number of ECO units) is used in subsequent calculations of energy usage and savings. The second, yet more significant, suggested change in the evaluation algorithms for all desiccant dehumidification ECOs is ***not*** to assume that exit air stream conditions are at 75 °F and 45 percent relative humidity (the indoor conditions). Instead, specific relationships to calculate the temperature and relative humidity are recommended.

Units Calculation. Although the units calculation (numecouni) is used in subsequent calculations of energy usage and savings, the capacity of the desiccant dehumidifier (A_{11}, cfm/unit) is not accounted for in the units calculation. Also, the penetration factor adjustment (1-penfac) and percent locations applicable (A_{12}) are applied only to the final term of the units calculation (common facilities area). After examining other ECO algorithms, it is clear that the intent here is to apply these two adjustments to the total area, and not just to the common facilities area.

The following relationship should be used, which will account for changes in unit capacity as well as properly applying the penetration factor and locations applicable percentage. This relationship is based on an assumption that the existing units calculation is implicitly based on a unit capacity of 12000 cfm:

$$\begin{aligned}\text{numecouni} = \Bigg(&2\frac{A_2}{100}\frac{K_T}{22} + 3\frac{A_4}{100}\frac{K_R}{36} + \frac{A_3}{100}\frac{K_H}{16} \\ &+ 1.25\frac{A_6}{100}\frac{K_A}{15} + 3\frac{A_1}{100}\frac{K_B}{45.6} + \frac{A_5}{100}\frac{K_C}{10.2}\Bigg)(1-\text{penfac})A_{12}\frac{12000}{A_{11}}\end{aligned}$$

where:

K_X are installation areas (Ksf) with the subscripts representing:

T Training (traare)

R Research, Development, and Testing (rdtare)

H Hospital and Medical (hosmedare)

A Administrative (admare)

B Barracks (barare)

C Common Facilities (comfacare).

Cooling Season Days Check. The check for cooseaday < 10 should occur after, or as a part of, the units calculation. It appears that the intent of this check is to

“disable” the ECO calculations when this test is satisfied. Forcing the units to zero is likely a preferable way to achieve this.

Temperature and Relative Humidity Calculation. It is recommended that the following modified relationships among dry and wet bulb temperatures (T_{DB} and T_{WB}), annual dry bulb hours (HDB), air stream enthalpies (hIN and hOUT), and humidity ratios (WIN and WOUT) be incorporated into the revised REEP program as far as evaluation algorithms for all desiccant dehumidification ECOs are concerned:

$$T_{WB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\bar{T}_{WB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\bar{T}_{WB_{85-89}} + 459.67$$

$$T_{DB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\bar{T}_{DB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\bar{T}_{DB_{85-89}} + 459.67$$

where the average dry-bulb temperature, $\bar{T}_{DB}$, for the temperature bins 80-84 and 85-90 should be 82.5 and 87.5 °F, respectively. This assumes that the temperature bin boundaries are (80,85) and (85,90).

Further, PWS (water vapor saturation pressure) relationship needs to be in terms of T_{DB}, and not T_{WB}.

Next, the relationships for air humidity ratio and enthalpies should be defined as follows:

$$W = \frac{\left(1093 - 0.556(T_{WB} - 459.67)W_S - 0.24(T_{DB} - T_{WB})\right)}{1093 + 0.444(T_{DB} - 459.67) - (T_{WB} - 459.67)},$$

$$h_{IN} = 0.24(T_{DB} - 459.67)\,W\left(1061 + 0.444(T_{DB} - 459.67)\right), \text{ and}$$

$$h_{OUT} = 0.24T_{DB_{OUT}} + W_{OUT}\left(1061 + 0.444T_{DB_{OUT}}\right)$$

where:

$T_{DB_{OUT}}$ = T_{DB} for liquid desiccant systems with cooling tower

= 0.84551W + 0.8375 T_{DB} + 46.768 for solid desiccant rotary wheel systems

and

W_{OUT} = 0.45W for liquid desiccant systems with cooling tower

= $0.708105W + 0.066072\ T_{DB} - 8.02371$ for solid desiccant rotary wheel systems.

B03. Desiccant Cooling - Dehumidification System (> 100 RT)

Background. A desiccant cooling system removes large amounts of moisture from incoming air before it reaches the cooling coil, thereby reducing the latent load on the system, and hence saving energy. The air is first passed through a desiccant wheel, which removes moisture and lowers the relative humidity. The desiccant wheel is regenerated using gas or waste heat. As the moisture is removed, the air temperature increases. It must be subsequently cooled by a sensible heat exchanger (wheel) which, in turn, is cooled by (for example) building exhaust air. The desiccant wheel can be regenerated using waste heat from a nearby boiler or gas engine. (However, this is not taken into account in this analysis.)

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	Kathabar Inc.
Type/Brand Name	1600 FV / Kathapac
Unit Capacity	**16,000 [cfm]**
Installed Cost	**220,000 [$] (conditioner unit with a regenerator)**
Economic Life	20 [years]
Unit Elect. Consumption	**13.4 [kW]**
Unit Gas Consumption	**1.075 [MBtu/hr]**
Recurring Cost	1 [% of Capital Cost/year]
Demand Diversity Factor	0.8
Chiller COP	3
Discount Quantity	5 [units]

Facility Assumptions. Latent load (dehumidification) on the building is taken care of by this system. First the average outdoor humidity ratio for each location summer season is calculated. Next, the enthalpy of the incoming air stream and the air stream leaving the desiccant wheel are calculated. This also assumes an average room control temperature of 75 °F and relative humidity of 45 percent with 20 percent make-up air in the air handling unit. Sensible cooling (the remaining load on the building), if needed to reach the 75 °F indoors, would be provided by combining the systems with engine-driven or absorption chillers or air conditioners.

Ventilation	12 [hrs/day]
Barracks (% Applicable)	33%
Training (% Applicable)	20%
R&D (% Applicable)	80%
Administration (% Applicable)	50%
Community (% Applicable)	50%
Medical (% Applicable)	100%
Locations (% Applicable)	100%

Algorithm Modifications. Since it is suggested that multiple sizes of desiccant dehumidification ECOs be incorporated in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

The first suggested algorithm change pertains to the way the variable numecouni (number of ECO units) is used in subsequent calculations of energy usage and savings. The second, yet more significant, suggested change in the evaluation algorithms for all desiccant dehumidification ECOs is not to assume that exit air stream conditions are at 75 °F and 45 percent relative humidity (the indoor conditions). Instead, specific relationships to calculate the temperature and relative humidity are recommended.

Units Calculation. Although the units calculation (numecouni) is used in subsequent calculations of energy usage and savings, the capacity of the desiccant dehumidifier (A_{11}, cfm/unit) is not accounted for in the units calculation. Also, the penetration factor adjustment (1-penfac) and percent locations applicable (A_{12}) are applied only to the final term of the units calculation (common facilities area). After examining other ECO algorithms, it is clear that the intent here is to apply these two adjustments to the total area, and not just to the common facilities area.

The following relationship should be used, which will account for changes in unit capacity as well as properly applying the penetration factor and locations applicable percentage. This relationship is based on an assumption that the existing units calculation is implicitly based on a unit capacity of 12000 cfm.

$$\text{numecouni} = \left(2\frac{A_2}{100}\frac{K_T}{22} + 3\frac{A_4}{100}\frac{K_R}{36} + \frac{A_3}{100}\frac{K_H}{16} + 1.25\frac{A_6}{100}\frac{K_A}{15} + 3\frac{A_1}{100}\frac{K_B}{45.6} + \frac{A_5}{100}\frac{K_C}{10.2} \right)(1-\text{penfac})A_{12}\frac{12000}{A_{11}}$$

where K_X are installation areas (Ksf) with the subscripts representing:

T Training (traare)

R Research, Development, and Testing (rdtare)

H Hospital and Medical (hosmedare)

A Administrative (admare)

B Barracks (barare)

C Common Facilities (comfacare).

Cooling Season Days Check. The check for cooseaday < 10 should occur after, or as a part of, the units calculation. It appears that the intent of this check is to "disable" the ECO calculations when this test is satisfied. Forcing the units to zero is likely a preferable way to achieve this.

Temperature and Relative Humidity Calculation. It is recommended that the following modified relationships among dry and wet bulb temperatures (T_{DB} and T_{WB}), annual dry bulb hours (H_{DB}), air stream enthalpies (h_{IN} and h_{OUT}), and humidity ratios (W_{IN} and W_{OUT}) be incorporated into the revised REEP program as far as evaluation algorithms for all desiccant dehumidification ECOs are concerned:

$$T_{WB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{WB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{WB_{85-89}} + 459.67$$

$$T_{DB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{DB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{T}_{DB_{85-89}} + 459.67$$

where the average dry-bulb temperature, $\overline{T}_{DB}$, for the temperature bins 80-84 and 85-90 should be 82.5 and 87.5 °F, respectively. This assumes that the temperature bin boundaries are (80,85) and (85,90).

Further, P_{WS} (water vapor saturation pressure) relationship needs to be in terms of T_{DB}, and not T_{WB}.

Next, the relationships for air humidity ratio and enthalpies should be defined as follows:

$$W = \frac{(1093 - 0.556(T_{WB} - 459.67)W_S - 0.24(T_{DB} - T_{WB}))}{1093 + 0.444(T_{DB} - 459.67) - (T_{WB} - 459.67)},$$

$$h_{IN} = 0.24(T_{DB} - 459.67)\, W\left(1061 + 0.444(T_{DB} - 459.67)\right), \text{ and}$$

$$h_{OUT} = 0.24 T_{DB_{OUT}} + W_{OUT}\left(1061 + 0.444 T_{DB_{OUT}}\right)$$

where:

$T_{DB_{OUT}}$ = T_{DB} for liquid desiccant systems with cooling tower

= $0.84551W + 0.8375T_{DB} + 46.768$ for solid desiccant rotary wheel systems

and

W_{OUT} = $0.45W$ for liquid desiccant systems with cooling tower

= $0.708105W + 0.066072T_{DB} - 8.02371$ for solid desiccant rotary wheel systems

B04. Desiccant Cooling - Sensible and Latent Cooling (5 to 25 RT)

Background. A desiccant cooling system removes large amounts of moisture from incoming air before it reaches the cooling coil, thereby reducing the latent load on the system, and hence saving energy. The air is first passed through a desiccant wheel, which removes moisture and lowers the relative humidity. The desiccant wheel is regenerated using gas or waste heat. As the moisture is removed, the air temperature increases. It must be subsequently cooled by a sensible heat exchanger (wheel) which, in turn, is cooled by (for example) building exhaust air. The desiccant wheel can be regenerated using waste heat from a nearby boiler or gas engine. (However, this is not taken into account in this analysis.)

The selected ECO offers all the benefits of natural gas-fired desiccant cooling in a compact, energy-efficient package. It has enough ventilation capacity to serve as a standalone air conditioning system that meets both current and proposed IAQ guidelines. Further, the selected latent air conditioning system is capable of very effective dehumidification, heating, and partial cooling of sensible load without the use of refrigerants or a compressor. This ECO is designed for places where separate control of temperature and humidity can bring about improvements in building conditions and energy efficiency, and where large quantities of make-up air is an important consideration. Rotary-type, continuous-refrigeration dehumidifier wheel (latent cooling); rotary-generative heat exchanger wheel (sensible cooling); indirect evaporative cooling system; adjustable blowers, heating coils, filters, and gas-fired boiler are a few of the many reasons for the selection of this particular ECO. Finally, this technology is designed for roof or curb mounting, and is microprocessor-controlled.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	ENGELHARD/ICC
Type/Brand Name	DC 050, DESERTCOOL™
Unit Capacity	**5,000 [cfm]**
Installed Cost	**37,000 [$]**
Economic Life	**15 [years]**
Unit Elect. Consumption	**13.8 [kW]**
Unit Gas Consumption	**0.50 [MBtu/hour]**
Unit Water Consumption	**0.87 [gal/RT]**
Recurring Cost	1 [% of Capital Cost/year]
Demand Diversity Factor	0.8
Chiller COP	3
Thermal COP	**1.3 [at full load]**
Discount Quantity	5 [units]

Facility Assumptions. All facility assumptions, except air delivery conditions, remain the same for this ECO.

Locations. (% Applicable) 100%

Air Delivery Conditions. 55°F D.B. / 53°F W.B.

Algorithm Modifications. Since it is suggested that multiple sizes of desiccant cooling ECOs be included in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

The first suggested algorithm change pertains to the way the variable numecouni (number of ECO units) is used. The second, yet more significant, suggested change in the evaluation algorithms for all desiccant cooling ECOs is not to assume that exit air stream conditions are at 75 °F and 45 percent relative humidity (the indoor conditions). Instead, specific relationships to calculate the temperature and relative humidity are recommended. The last, but not the least, suggested change deals with the calculations of energy consumed (or saved).

Units Calculation. The capacity of the enthalpy wheel (cfm/unit) is presented in the REEP manual, but is not accounted for in the ECO algorithm, nor is it used in the units calculation. Also, the penetration factor adjustment (1-penfac) and percent locations applicable (A_{12}) are applied only to the final term of the

units calculation (common facilities area). After examining other ECO algorithms, it is clear that the intent here is to apply these two adjustments to the total area, and not just to the common facilities area.

The following relationship should be used, which will account for changes in unit capacity as well as properly applying the penetration factor and locations applicable percentage. A_{13} would be a new assumption representing the unit capacity (cfm/unit).

$$\text{numecouni} = \left(2\frac{A_2}{100}\frac{K_T}{22} + 3\frac{A_4}{100}\frac{K_R}{36} + \frac{A_3}{100}\frac{K_H}{16} + 1.25\frac{A_6}{100}\frac{K_A}{15} + 3\frac{A_1}{100}\frac{K_B}{45.6} + \frac{A_5}{100}\frac{K_C}{10.2}\right)(1-\text{penfac})A_{12}\frac{1500}{A_{13}}$$

where K_X are installation areas (Ksf) with the subscripts representing:

T Training (traare)

R Research, Development, and Testing (rdtare)

H Hospital and Medical (hosmedare)

A Administrative (admare)

B Barracks (barare)

C Common Facilities (comfacare).

The units calculation is not used in subsequent calculations of heating or cooling energy saved. Rather, these savings are based on the assumed ventilation rate (A11, cfm/ksf).

Temperature and Relative Humidity Calculation. It is recommended that the following modified relationships among dry and wet bulb temperatures (T_{DB} and T_{WB}), annual dry bulb hours (H_{DB}), air stream enthalpies (h_{IN} and h_{OUT}), and humidity ratios (W_{IN} and W_{OUT}) be incorporated into the revised REEP program as far as evaluation algorithms for all desiccant sensible and latent cooling and enthalpy recovery wheel ECOs are concerned:

$$T_{WB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{T}_{WB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{T}_{WB_{85-89}} + 459.67$$

$$T_{DB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{T}_{DB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{T}_{DB_{85-89}} + 459.67$$

where H_{DBx} is the annual dry bulb hours in the X temperature range bi, and $\overline{T}_{WB_X}$ and $\overline{T}_{DB_X}$ are the mean coincident wet and dry, respectively, bulb temperatures in the X temperature range bin.

The average dry-bulb temperature, $\overline{T}_{DB}$, for the temperature bins 80-84 and 85-90 should be 82.5 and 87.5 °F, respectively. This assumes that the temperature bin boundaries are (80,85) and (85,90).

Further, P_{WS} (water vapor saturation pressure) relationship needs to be in terms of T_{DB}, and not T_{WB}.

Next, the relationship for air humidity ratio should be defined as follows:

$$W = \frac{\left(1093 - 0.556(T_{WB} - 459.67)W_S - 0.24(T_{DB} - T_{WB})\right)}{1093 + 0.444(T_{DB} - 459.67) - (T_{WB} - 459.67)}.$$

Energy Calculation. The remaining modified relationships pertain to the determination of unit demand, and energy usage and savings. Unit demand has been adjusted to represent the demand per unit, which can now vary with its capacity (cfm/unit).

$$\text{Udem} = A_{11} \times 60 \times 0.075 \times \Delta H \frac{A_{13}}{1500}$$

where:

A11 is assumption 11 (ventilation rate),

A13 is assumption 13 (unit capacity, cfm), and

ΔH = Change in enthalpy which, in turn, is given by the following equation:

$$\Delta H = 0.24\left(T_O - T_{EC}\right) + 1061\left(W - W_{EC}\right) + 0.444\left(WT_O - W_{EC}T_{EC}\right)$$

where:

TO is T_{DB} converted to °F,

TEC is the indoor air exhaust temperature during cooling season (75 °F)

WEC is the indoor air humidity ratio

WEC, in turn, must be calculated from the exhaust air conditions as follows:

$$W_{EC} = 0.62198 \frac{P_{W_{EC}}}{P_{AMB} - P_{W_{EC}}}$$

where: $P_{W_{EC}} = \frac{RH_{EC}}{100} P_{WS_{EC}}$

PWSEC represents the indoor air water saturation pressure, and is calculated using PWS relationship, but with TEC in °R, and not in °F.

Heating energy saved is modified to more accurately determine the "degree-days" needed for the calculation.

$$\text{Heating Energy Saved} = \eta_s \dot{H}_{SENS}\left(T_{EH}D_H - (65D_H - HDD)\right) \times KSF_{NET}$$

where:

ηs is the efficiency of sensible heat recovery (assumption 9),

TEH is the indoor air exhaust temperature during heating season (68 °F)

DH is the heating season days

ksfnet is the weighted sum of the space to be conditioned (per current REEP version)

Cooling energy saved is modified to reflect the changes in the Udem calculation:

$$\text{Cooling Energy Saved} = \eta_h \times Udem \times H_{DB>80} \times KSF_{NET} \frac{1500}{A_{13} 10^6}$$

where:

ηh is the efficiency of enthalpy recovery,

H_{DB}>80 is the Summer A/C Criteria Dry Bulb Hours > 80 °F (per sacdbh)

KSFNET is the weighted sum of the space to be conditioned (per current REEP version)

Summer demand saved is calculated from cooling energy saved, as is the case in several other ECO algorithms.

$$\text{Summer Demand Saved} = \frac{\text{Cooling Energy Saved}}{H_{DB>80} A_7} \frac{10^6}{3412}$$

where the final term above contains the element 3412 Btu/kWh.

To further improve the screening/evaluation of desiccant cooling systems, it is suggested that the first-order approximation of part-load performance be taken into consideration. This can be achieved by supplementing the modified screening/evaluation algorithm for the desiccant dehumidification ECOs (ECO Nos. F01 and B01 through B03) with the improved thermal efficiencies of a sensible heat exchanger (usually in the range of 85 to 92 percent) and evaporation pads (degree of humidification of both streams).

Sources. "Natural Gas Cooling Equipment Guide," 4th ed., April 1996, American Gas Cooling Center, 1515 Wilson Blvd., Arlington, VA 22209.

B05. Desiccant Cooling - Sensible and Latent Cooling (25 to 100 RT)

Background. A desiccant cooling system removes large amounts of moisture from incoming air before it reaches the cooling coil, thereby reducing the latent load on the system, and hence saving energy. The air is first passed through a desiccant wheel, which removes moisture and lowers the relative humidity. The desiccant wheel is regenerated using gas or waste heat. As the moisture is removed, the air temperature increases. It must be subsequently cooled by a sensible heat exchanger (wheel) which, in turn, is cooled by (for example) building exhaust air. The desiccant wheel can be regenerated using waste heat from a nearby boiler or gas engine. (However, this is not taken into account in this analysis.)

The selected ECO offers all the benefits of natural gas-fired desiccant cooling in a compact, energy-efficient package. It has enough ventilation capacity to serve as a standalone air conditioning system that meets both current and proposed IAQ guidelines. Further, the selected latent air conditioning system is capable of very effective dehumidification, heating, and partial cooling of sensible load without the use of refrigerants or a compressor. This ECO is designed for places where separate control of temperature and humidity can bring about improvements in building conditions and energy efficiency, and where large quantities of make-up air is an important consideration. Rotary-type,

continuous-refrigeration dehumidifier wheel (latent cooling); rotary-generative heat exchanger wheel (sensible cooling); indirect evaporative cooling system; adjustable blowers, heating coils, filters, and gas-fired boiler are a few of the many reasons for the selection of this particular ECO. Finally, this technology is designed for roof or curb mounting, and is microprocessor controlled.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	ENGELHARD/ICC
Type/Brand Name	DC 100, DESERTCOOL™
Unit Capacity	**10,000 [cfm]**
Installed Cost	**60,000 [$]**
Economic Life	**15 [years]**
Unit Elect. Consumption	**20.0 [kW]**
Unit Gas Consumption	**0.81 [MBtu/hour]**
Unit Water Consumption	**0.87 [gal/RT]**
Recurring Cost	1 [% of Capital Cost/year]
Demand Diversity Factor	0.8
Chiller COP	3
Thermal COP	**1.3 [at full load]**
Discount Quantity	5 [units]

Facility Assumptions. All facility assumptions, except air delivery conditions, remain the same for this ECO.

Locations (% Applicable) 100%

Air Delivery Conditions 55°F D.B. / 53°F W.B.

Algorithm Modifications. Since it is suggested that multiple sizes of desiccant cooling ECOs be included in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

The first suggested algorithm change pertains to the way the variable numecouni (number of ECO units) is used. The second, yet more significant, suggested change in the evaluation algorithms for all desiccant cooling ECOs is not to assume that exit air stream conditions are at 75 °F and 45 percent relative humidity (the indoor conditions). Instead, specific relationships to calculate the temperature and relative humidity are recommended. The last, but not the

least, suggested change deals with the calculations of energy consumed (or saved).

Units Calculation. The capacity of the enthalpy wheel (cfm/unit) is presented in the REEP manual, but is not accounted for in the ECO algorithm, nor is it used in the units calculation. Also, the penetration factor adjustment (1-penfac) and percent locations applicable (A_{12}) are applied only to the final term of the units calculation (common facilities area). After examining other ECO algorithms, it is clear that the intent here is to apply these two adjustments to the total area, and not just to the common facilities area.

The following relationship should be used, which will account for changes in unit capacity as well as properly applying the penetration factor and locations applicable percentage. A_{13} would be a new assumption representing the unit capacity (cfm/unit).

$$\text{numecouni} = \left(2\frac{A_2}{100}\frac{K_T}{22} + 3\frac{A_4}{100}\frac{K_R}{36} + \frac{A_3}{100}\frac{K_H}{16} + 1.25\frac{A_6}{100}\frac{K_A}{15} + 3\frac{A_1}{100}\frac{K_B}{45.6} + \frac{A_5}{100}\frac{K_C}{10.2}\right)(1-\text{penfac})A_{12}\frac{1500}{A_{13}}$$

where K_X are installation areas (Ksf) with the subscripts representing

T Training (traare)

R Research, Development, and Testing (rdtare)

H Hospital and Medical (hosmedare)

A Administrative (admare)

B Barracks (barare)

C Common Facilities (comfacare).

The units calculation is not used in subsequent calculations of heating or cooling energy saved. Rather, these savings are based on the assumed ventilation rate (A11, cfm/ksf).

Temperature and Relative Humidity Calculation. It is recommended that the following modified relationships among dry and wet bulb temperatures (T_{DB} and T_{WB}), annual dry bulb hours (H_{DB}), air stream enthalpies (h_{IN} and h_{OUT}), and humidity ratios (W_{IN} and W_{OUT}) be incorporated into the revised REEP program as far as evaluation algorithms for all desiccant sensible and latent cooling and enthalpy recovery wheel ECOs are concerned:

$$T_{WB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{T}_{WB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{T}_{WB_{85-89}} + 459.67$$

$$T_{DB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{T}_{DB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}}\overline{T}_{DB_{85-89}} + 459.67$$

where H_{DBx} is the annual dry bulb hours in the X temperature range bi, and

$\overline{T}_{WB_X}$ and $\overline{T}_{DB_X}$ are the mean coincident wet and dry, respectively, bulb temperatures in the X temperature range bin.

The average dry-bulb temperature, $\overline{T}_{DB}$, for the temperature bins 80-84 and 85-90 should be 82.5 and 87.5 °F, respectively. This assumes that the temperature bin boundaries are (80,85) and (85,90).

Further, P_{WS} (water vapor saturation pressure) relationship needs to be in terms of T_{DB}, and not T_{WB}.

Next, the relationship for air humidity ratio should be defined:

$$W = \frac{(1093 - 0.556(T_{WB} - 459.67)W_S - 0.24(T_{DB} - T_{WB}))}{1093 + 0.444(T_{DB} - 459.67) - (T_{WB} - 459.67)}$$

Energy Calculation. The remaining modified relationships pertain to the determination of unit demand, and energy usage and savings. Unit demand has been adjusted to represent the demand per unit, which can now vary with its capacity (cfm/unit).

$$\text{Udem} = A_{11} \times 60 \times 0.075 \times \Delta H \frac{A_{13}}{1500}$$

where:

A_{11} is assumption 11 (ventilation rate)

A_{13} is assumption 13 (unit capacity, cfm)

ΔH = Change in enthalpy which, in turn, is given by the following equation:

$$\Delta H = 0.24(T_O - T_{EC}) + 1061(W - W_{EC}) + 0.444(WT_O - W_{EC}T_{EC}).$$

where:

$T_O = T_{DB}$ converted to °F

T_{EC} = the indoor air exhaust temperature during cooling season (75 °F)

W_{EC} = the indoor air humidity ratio.

W_{EC}, in turn, must be calculated from the exhaust air conditions as follows:

$$W_{EC} = 0.62198 \frac{P_{W_{EC}}}{P_{AMB} - P_{W_{EC}}}$$

where: $P_{W_{EC}} = \frac{RH_{EC}}{100} P_{WS_{EC}}$

$P_{WS_{EC}}$ represents the indoor air water saturation pressure, and is calculated using P_{WS} relationship but with T_{EC} in °R, and not in °F. Heating energy saved is modified to more accurately determine the "degree-days" needed for the calculation.

$$\text{Heating Energy Saved} = \eta_S H_{SENS}\left(T_{EH}D_H - \left(65D_H - HDD\right)\right) \times KSF_{NET}$$

where:

η_s is the efficiency of sensible heat recovery (assumption 9)

T_{EH} is the indoor air exhaust temperature during heating season (68 °F),

D_H is the heating season days, and

KSF_{NET} is the weighted sum of the space to be conditioned (per current REEP version)

Cooling energy saved is modified to reflect the changes in the Udem calculation.

KSF_{NET} is the weighted sum of the space to be conditioned (per current REEP version)

$$CoolingEnergySaved = \eta_h \times Udem \times H_{DB>80} \times KSF_{NET} \frac{1500}{A_{13}10^6}$$

where:

η_h is the efficiency of enthalpy recovery,

$H_{DB>80}$ is the Summer A/C Criteria Dry Bulb Hours > 80 °F (per sacdbh)

Summer demand saved is calculated from cooling energy saved, as is the case in several other ECO algorithms:

$$\text{Summer Demand Saved} = \frac{\text{Cooling Energy Saved}}{H_{DB>80} A_7} \frac{10^6}{3412}$$

where the final term above contains the element 3412 Btu/kWh.

To further improve the screening/evaluation of desiccant cooling systems, it is suggested that the first-order approximation of part-load performance be taken into consideration. This can be achieved by supplementing the modified screening/evaluation algorithm for the desiccant dehumidification ECOs (ECO Nos. F01 and B01 through B03) with the improved thermal efficiencies of a sensible heat exchanger (usually in the range of 85 to 92 percent) and evaporation pads (degree of humidification of both streams).

Sources: "Natural Gas Cooling Equipment Guide," 4th ed., April 1996, American Gas Cooling Center, 1515 Wilson Blvd., Arlington, VA 22209.

B06. Desiccant Enthalpy Recovery Wheel (5 to 25 RT)

Background. A desiccant wheel is a rotating heat exchanger capable of transferring both sensible and latent heat and is often installed between the exhaust and make-up air streams. Humidity is kept in the building in the winter, moisture is transferred to the drier air stream. In the winter, incoming low-temperature air is warmed through the exchanger by the warmer exhaust air. In the summer, incoming hot humid air is cooled and dried by the exhaust air. Thus, a sensible heat savings is accomplished year-round, while a latent heat savings is achieved during the cooling season.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	Greenheck
Type/Brand Name	ERV 521S
Unit Capacity	3,000 [cfm]
Installed Cost	**11,000 [$]**
Economic Life	**20 [years]**
Recurring Cost per Unit	**50 [$/year]**
Ventilation Rate	100 [cfm/k sq ft]
Demand Diversity Factor	0.8

Chiller COP	3
Thermal COP	**1.3 [at full load]**
Efficiency of Sensible Heat Recovery	**75%**
Efficiency of Latent Heat Recovery	**75%**
Discount Quantity	30 [units]

Facility Assumptions. All facility assumptions, except air delivery conditions, remain the same for this ECO.

Locations (% Applicable, Adjacent Ductwork)	0.3%
Air Delivery Conditions	55°F D.B. / 53°F W.B.

Algorithm Modifications. The first suggested algorithm change pertains to the way the variable numecouni (number of ECO units) is used. The second, yet more significant, suggested change in the evaluation algorithms for all desiccant cooling ECOs is not to assume that exit air stream conditions are at 75 °F and 45 percent relative humidity (the indoor conditions). Instead, specific relationships to calculate the temperature and relative humidity are recommended. The last, but not the least, suggested change deals with the calculations of energy consumed (or saved).

Units Calculation. The capacity of the enthalpy wheel (cfm/unit) is presented in the REEP manual, but is not accounted for in the ECO algorithm, nor is it used in the units calculation. Also, the penetration factor adjustment (1-penfac) and percent locations applicable (A_{12}) are applied only to the final term of the units calculation (common facilities area). After examining other ECO algorithms, it is clear that the intent here is to apply these two adjustments to the total area, and not just to the common facilities area.

The following relationship should be used, which will account for changes in unit capacity as well as properly applying the penetration factor and locations applicable percentage. A_{13} would be a new assumption representing the unit capacity (cfm/unit).

$$\text{numecouni} = \left(2\frac{A_2}{100}\frac{K_T}{22} + 3\frac{A_4}{100}\frac{K_R}{36} + \frac{A_3}{100}\frac{K_H}{16} + 1.25\frac{A_6}{100}\frac{K_A}{15} + 3\frac{A_1}{100}\frac{K_B}{45.6} + \frac{A_5}{100}\frac{K_C}{10.2}\right)(1-\text{penfac})A_{12}\frac{1500}{A_{13}}$$

where K_X are installation areas (Ksf) with the subscripts representing:

T Training (traare)

R Research, Development, and Testing (rdtare)

H Hospital and Medical (hosmedare)

A Administrative (admare)

B Barracks (barare)

C Common Facilities (comfacare).

The units calculation is not used in subsequent calculations of heating or cooling energy saved. Rather, these savings are based on the assumed ventilation rate (A11, cfm/ksf).

Temperature and Relative Humidity Calculation. It is recommended that the following modified relationships among dry and wet bulb temperatures (T_{DB} and T_{WB}), annual dry bulb hours (H_{DB}), air stream enthalpies (h_{IN} and h_{OUT}), and humidity ratios (W_{IN} and W_{OUT}) be incorporated into the revised REEP program as far as evaluation algorithms for all desiccant sensible and latent cooling and enthalpy recovery wheel ECOs are concerned:

$$T_{WB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{\overline{T}}_{WB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{\overline{T}}_{WB_{85-89}} + 459.67$$

$$T_{DB} = \frac{H_{DB_{80-84}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{\overline{T}}_{DB_{80-84}} + \frac{H_{DB_{85-89}}}{H_{DB_{80-84}} + H_{DB_{85-89}}} \overline{\overline{T}}_{DB_{85-89}} + 459.67$$

where H_{DBx} is the annual dry bulb hours in the X temperature range bi, and $\overline{T}_{WB_X}$ and $\overline{T}_{DB_X}$ are the mean **coincident** wet and dry, respectively, bulb temperatures in the X temperature range bin.

The average dry-bulb temperature, $\overline{T}_{DB}$, for the temperature bins 80-84 and 85-90 should be 82.5 and 87.5 °F, respectively. This assumes that the temperature bin boundaries are (80,85) and (85,90).

Further, P_{WS} (water vapor saturation pressure) relationship needs to be in terms of T_{DB}, and not T_{WB}.

Next, the relationship for air humidity ratio should be defined:

$$W = \frac{(1093 - 0.556(T_{WB} - 459.67)W_S - 0.24(T_{DB} - T_{WB}))}{1093 + 0.444(T_{DB} - 459.67) - (T_{WB} - 459.67)}$$

Energy Calculation. The remaining modified relationships pertain to the determination of unit demand, and energy usage and savings. Unit demand has

been adjusted to represent the demand per unit, which can now vary with its capacity (cfm/unit):

$$Udem = A_{11} \times 60 \times 0.075 \times \Delta H \frac{A_{13}}{1500}$$

where:

A_{11} is assumption 11 (ventilation rate)

A_{13} is assumption 13 (unit capacity, cfm)

ΔH = Change in enthalpy, which, in turn, is given by the following equation:

$$\Delta H = 0.24\left(T_O - T_{EC}\right) + 1061\left(W - W_{EC}\right) + 0.444\left(WT_O - W_{EC}T_{EC}\right)$$

where:

T_O is T_{DB} converted to °F

T_{EC} is the indoor air exhaust temperature during cooling season (75 °F)

W_{EC} is the indoor air humidity ratio.

W_{EC}, in turn, must be calculated from the exhaust air conditions as follows:

$$W_{EC} = 0.62198 \frac{P_{W_{EC}}}{P_{AMB} - P_{W_{EC}}}$$

where:

$$P_{W_{EC}} = \frac{RH_{EC}}{100} P_{WS_{EC}}$$

$P_{WS_{EC}}$ represents the indoor air water saturation pressure, and is calculated using P_{WS} relationship but with T_{EC} in °R, and not in °F.

Heating energy saved is modified to more accurately determine the "degree-days" needed for the calculation.

$$\text{Heating Energy Saved} = \eta_s \dot{H}_{SENS}\left(T_{EH}D_H - \left(65D_H - HDD\right)\right) \times KSF_{NET}$$

where:

η_s is the efficiency of sensible heat recovery (assumption 9)

T_{EH} is the indoor air exhaust temperature during heating season (68 °F)

D_H is the heating season days

KSF_{NET} is the weighted sum of the space to be conditioned (per current REEP version).

Cooling energy saved is modified to reflect the changes in the Udem calculation.

$$\text{Cooling Energy Saved} = \eta_h \times \text{Udem} \times H_{DB>80} \times KSF_{NET} \frac{1500}{A_{13} 10^6}$$

where:

η_h is the efficiency of enthalpy recovery,

$H_{DB>80}$ is the Summer A/C Criteria Dry Bulb Hours > 80 °F (per sacdbh), and

KSF_{NET} is the weighted sum of the space to be conditioned (per current REEP version).

Summer demand saved is calculated from cooling energy saved, as is the case in several other ECO algorithms.

$$\text{Summer Demand Saved} = \frac{\text{Cooling Energy Saved}}{H_{DB>80} A_7} \frac{10^6}{3412}$$

where the final term above contains the element 3412 Btu/kWh.

Source. Direct contact with manufacturers.

B07. Infrared Radiant Heating System

Background. Buildings isolated from an installation's central heating network use about half of the Army's heating energy. The use of conventional heating technologies does not offer an optimum solution especially in hanger facilities with large amounts of open space. Infrared heating systems are ideal for such applications. A number of DOD installations have realized significant cost and energy savings by implementing this ECO. The selected technology is sealed, maintenance-free, vacuum vented, and features aluminized steel tubing for long life and dry tube construction to eliminate corrosive condensation. The system is also capable of zone control. Besides hangers, the selected ECO is suitable for factories, warehouses, recreatiónal facilities, and gymnasiums. It is suggested that this new ECO be incorporated into the revised version of the REEP program.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the

Notation Conventions section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	Combustion Research Corporation; Rochester Hill, Michigan
Type/Brand Name	REFLECT-O-RAY
Installed Cost per Unit	*17,500 [$] (incl. burner, 230' of 6" tubing, reflectors, hangers, and chains)*
Recurring Cost per Unit	*0.25 [% of capital cost/year]*
Heat Input Rate	*360,000 [Btu/hr]*
Thermal Efficiency	*87 [%]*
Surface Area Covered per Unit	*9.25 [KSF]*
Economic Life	*15 [years]*
Discount Quantity	10 [units]
Efficiency of Old Heating Plant	65 [%]

Facility Assumption. The following facility assumptions are suggested for this ECO:

Age of Existing Equipment 10 [years]

Height of Ceiling 40 [ft]

ECO Evaluation Algorithm. The approach to evaluating a facility for possible conversion to an infrared heating system is based on the following criteria:

- Age of existing equipment
- Type of heating system installed (e.g., steam forced air, direct-fired forced air, etc.)
- Height of ceiling
- Air infiltration rate
- Annual fuel oil consumption
- Fuel oil and natural gas costs.

The losses in the traditional forced air heating system are a result of conditioned air that escapes through infiltration and normal hanger/roll-up door opening and closing. In addition, the heated air rises above the normal training work area resulting in long boiler run hours, and the duration of reheating the space is significant once personnel and equipment entrance/exits are opened. Infrared heating savings are achieved due to the basic principle of infrared heating – heating objects, people, and concrete flooring (creeping/radiant heat), but not air. The Directorate of Public Works at Fort Eustis, VA, for example, has realized a 25 to 30 percent savings in its high bay conversions.

Analysis of conversion is based on historical usage data normalized by monthly Heating Degree Days (HDD). The algorithm used to calculate estimated savings is as follows:

Prior 3-year average Heating Season (HS) usage X ((30-year average HS HDD)/HS HDD)) X 25%

The resulting consumption is multiplied by current fuel rate and subtracted from the actual billing amount. The result is estimated infrared heating system savings due to reduced fuel consumption to condition the same high bay space.

On completion of conversion to infrared heating system, the estimated savings can be confirmed by comparing the normalized current year fuel usage by the following formula:

Annual Heating Season (HS) usage X ((30-year average HS HDD)/HS HDD))

The resulting consumption is multiplied by the current fuel rate and subtracted from the previous year normalized usage/cost calculation. The result is actual infrared heating system savings due to reduced fuel consumption. Note that changes in fuel oil and natural gas rates must be taken into account to obtain true savings comparison.

Source. DPW, U.S. Army Transportation Center, Fort Eustis, VA; Private communications with the manufacturer.

Utilities and Heating/Cooling Plants (ECO Nos. U01 through U18)

The following 18 ECOs are covered under this category:

U01. Cogeneration - Gas Turbine (< 5 MW)

U02. Cogeneration - Gas Turbine (5 to 20 MW)

U03. Cogeneration - Phosphoric Acid Fuel Cell

U04. Cogeneration - Reciprocating Engine (< 100 kW)

U05. Cogeneration - Reciprocating Engine (100 to 500 kW)

U06. Cogeneration - Reciprocating Engine (500 kW to 2 MW)

U07. Cogeneration - Reciprocating Engine (> 2 MW)

U08. Direct-Fired Gas Absorption Chiller (< 5 RT)

U09. Direct-Fired Gas Absorption Chiller (5 to 25 RT)

U10. Direct-Fired Gas Absorption Chiller (25 to 100 RT)

U11. Direct-Fired Gas Absorption Chiller (> 100 RT)

U12. Gas Engine-Driven Air Compressor

U13. Gas Engine-Driven Chiller (5 to 25 RT)

U14. Gas Engine-Driven Chiller (25 to 100 RT)

U15. Gas Engine-Driven Chiller (> 100 RT)

U16. High-Efficiency Gas Boiler (< 100 hp)

U17. High-Efficiency Gas Boiler (100 to 250 hp) U18. High-Efficiency Gas Boiler (> 250 hp).

Screening/Evaluation of Advanced Gas-Fired Cogeneration Technologies (ECO Nos. U01, U02, and U04 through U07)

This section addresses screening/evaluation of both gas turbine- and engine-driven cogeneration technologies. Since the discussion presented below is applicable to multiple ECOs, it is not repeated under each applicable ECO.

To be consistent with the current algorithms for gas turbine- and engine-driven cogeneration ECOs in the REEP Program, it is assumed that the selected advanced gas-fired cogeneration technology will be sized for continuous operation throughout the year, and any shortfall in thermal and electric energy needs will be met through currently available conventional sources, i.e., boiler (for thermal load) and utility grid (for electric load), respectively. The following pages describe the development of an evaluation algorithm for cogeneration ECOs:

Let:

H	=	Annual thermal energy requirement	(MBtu / Year)
E	=	Annual electric energy requirement	(kWh / Year)
h	=	Thermal efficiency of the boiler	(%)
E_i	=	Electric load demand at level "i"	(kW)
h_i	=	No. of hours for which electric demand is at level "i"	(hours)
n	=	No. of different electric demand levels in a typical year	
R	=	Heat rate for the selected cogeneration technology	(MBtu/kWh)
TR	=	Thermal recovery rate for selected cogen. technology	(%)
p_g	=	Price of natural gas	($/MBtu)
p_e	=	Price of electricity	($/kWh)
I	=	Installed cost of the selected cogeneration technology	($)
D	=	Electric demand charge	($/kW/Month)
d	=	Real discount rate	
L	=	Economic life of the selected cogeneration technology	(Years)
M	=	Maintenance cost for the selected cogen. technology	($/kWh)

Figure 8 depicts the comparison of conventional power generation with an advanced gas-fired cogeneration technology.

Annual electric energy requirement can now be calculated as:

$$\sum_{i=1}^{n} E_i h_i (kWh)$$

Using conventional technology, the cost of meeting the annual thermal and electric energy requirements can then be calculated:

$$Annual\ cost\ of\ meeting\ thermal\ demand = A_g = (p_g * H / h) \qquad \text{(\$/year)}$$

and

$$Annual\ cost\ of\ meeting\ electrical\ demand = A_e = \left(P_e * E + D * \sum_{j=1}^{12} E_j \right) \qquad \text{(\$/year)}$$

where E_j = Peak electricity demand level in month "j".

For simplicity, let us now assume that the selected cogeneration technology is designed to meet the thermal energy load requirement and any shortfall in electric energy requirement would be fulfilled through power purchased from the local utility.

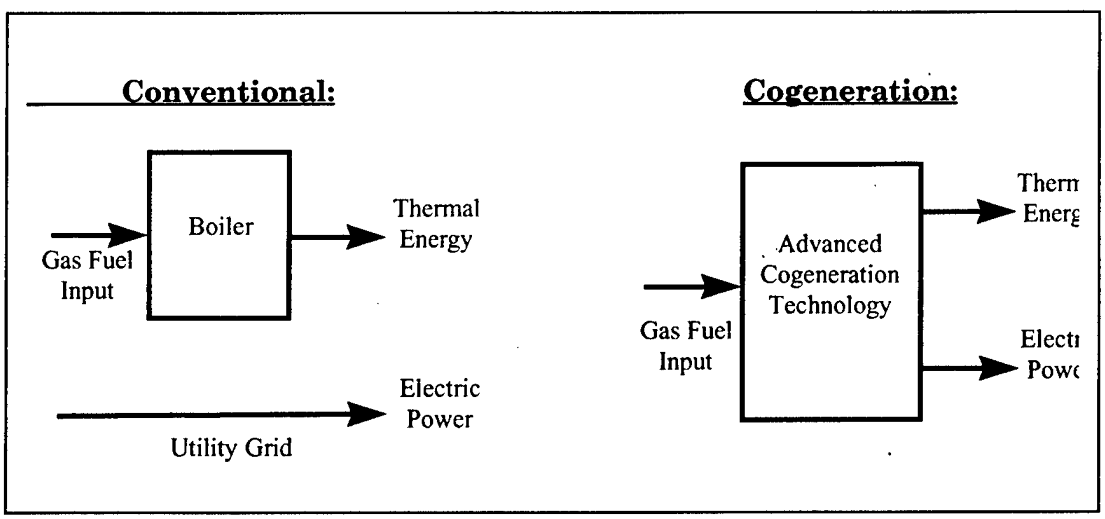

Figure 8. Comparison of "conventional" power generation with "cogeneration" technology.

Now, to produce H MBtu/year of thermal output, the selected cogeneration technology will require gas fuel input equal to (H/TR) MBtu/year, and will generate E_c = ([H/TR]*[1/R]) kWh/year of electric energy. Thus, the electricity demand shortfall in a typical year can be represented as ($E - E_c$), where E is the total annual electric energy requirement. The electric demand charge will, therefore, be now applied only to the amount (E_j - [E_c / 12]) kWh instead of E_j kWh.

The total cost of meeting both the thermal and electric energy requirement at a given military installation by implementing the selected advanced gas-fired cogeneration technology, therefore, can be calculated as:

$$A_c = (p_g * H / TR) + M * E_c + p_e * (E - E_c) + D * \sum_{J=1}^{12} (E_j - (E_c / 12)) \qquad (\$/\text{Year})$$

Thus, the net annual savings of adopting the selected cogeneration technology would be:

$$S = (A_g + A_e - A_c) \qquad (\$/\text{Year})$$

Given that the economic life of the selected cogeneration technology is L years and that its installed cost is I dollars, one can calculate the present value of savings to determine whether the selected cogeneration technology would be economically viable. Specifically, the present value of savings (or the "Net Present Value," NPV) is given by:

$$\text{NPV} = \sum_{1}^{L} S/(1+d)^k \qquad (\$)$$

If NPV > I, then, and only then, the selected advanced gas-fired cogeneration technology would be judged an economically viable option. It should be noted that these simplified calculations do not account for the downtime that would be necessary for scheduled maintenance and/or unscheduled repair of the cogeneration technology.

U01. Cogeneration - Gas Turbine (< 5 MW)

Background. Many applications require both electricity and thermal energy. Central energy plants are a prime application at DOD facilities. Cogeneration systems can be sized to meet the thermal load and provide the electricity to the base utility grid. Typical installations would be capable of consuming many MWs of cogenerated electricity without exporting power off the base. The ability

of gas turbine generator sets to run efficiently makes them ideal for base load power generation and to increase electrical reliability at the installation. Smaller size turbine-driven systems (< 3 MW) overlap considerably with engine-driven cogeneration systems.

Gas turbine cogeneration systems are available in electrical capacities of several hundred kWs to tens of MWs as a single package. Multiple units can be connected in the same system for increased capacity. Gas turbine cogeneration systems have been used successfully for many applications. Payback periods vary considerably depending on the local gas and electric rates, but tend to be appropriate where the demand charge is high. The following gas turbine-driven system has been selected for its high thermal efficiency, lower emission levels, and the availability of water injection and nozzle steam injection options.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer and Model Number	Allison / US Turbine Corporation; UST5000
Prime Mover Model Number	501-KB7
Rating ISO Base (@ Sea Level, 60 °F, 60% RH)	4,944 kW
Heat Rate (LHV)	**11,737 Btu/kWh**
Fuel Flow (LHV)	57.296 MBtu/Hour
Thermal Efficiency	34%
Pressure Ratio	13.5
Turbine Speed	14,589 RPM
Exhaust Gas Temperature	996 °F
Exhaust Gas Flow	45.1 Lb/Sec
NOx Emissions	125 PPMv (ref 15% O2)
Installed Cost	**1,000 - 1,200 $/kW (with steam injection)**
O&M Cost	**0.005 $/kWh**
Economic Life	15 - 20 Years
Discount Quantity	3 units
Demand Diversity Factor	1.0

Facility Assumptions. It is assumed that for this application the gas turbine cogeneration system will operate continuously and provide maximum power. Also assumed is that the DOD installation is large enough that all electricity generated by the cogeneration system will be used on base and none will be exported to the utility grid. Normal scheduled maintenance is performed during off-peak periods and full credit for the demand reduction is given for the rated capacity of the cogeneration set. Also, a user selected fraction of the available thermal energy is assumed to be used.

Annual Hours of Operation	8,650
Percent Thermal Recovery	50%
Annual Hours for Thermal Recovery	8,650
Boiler Efficiency	70%
Average Capacity of Large Gas Boiler Plant	50 MBtu/hr
Smallest Hospital Area	**30 k sq ft**

Algorithm Modifications. For a detailed discussion of the recommended modifications for this ECO, see Screening/Evaluation of Advanced Gas-Fired Cogeneration Technologies section above. Since it is suggested that multiple sizes of gas turbine-driven cogeneration ECOs be incorporated in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

This ECO algorithm contains "hard coding" of the cogeneration unit size. Because the new ECOs will use the same ECO algorithm, this "hard coding" needs to be remedied. The following relationships show the modifications to the units calculation.

demandcheck = 0.33*xelekwpdem/xassum09v
electcheck = 0.33*xeleserq/(xassum09v/1000)/xassum02v

Also, three other calculations need the "hard coding" of 5000 kW replaced with assumption 9. These are the calculations of baseload demand saved (basdemsav), electric fuel saved (eleenesav), and gas fuel saved (gasenesav).

Because the current version of the REEP program does not allow the input of values with more than 6 digits to the left of the decimal place, the algorithm multiplied the initial cost (inicos) by 10 to account for this. It is our understanding that this limitation will be removed in the next version of the REEP program.

The change to the smallest hospital area (assumption 8) reflects an apparent mismatch between the assumption value (originally 30,000 sq ft) and the units for hospital area in the installation data, which is in thousands of square feet.

U02. Cogeneration - Gas Turbine (5 to 20 MW)

Background. Many applications require both electricity and thermal energy. Central energy plants are a prime application at DOD facilities. Cogeneration systems can be sized to meet the thermal load and provide the electricity to the

base utility grid. Typical installations would be capable of consuming many MWs of cogenerated electricity without exporting power off the base. The ability of gas turbine generator sets to run efficiently makes them ideal for base load power generation and to increase electrical reliability at the installation. Smaller size turbine-driven systems (< 3 MW) overlap considerably with engine-driven cogeneration systems.

Gas turbine cogeneration systems are available in electrical capacities of several hundred kWs to tens of MWs as a single package. Multiple units can be connected in the same system for increased capacity.

Gas turbine cogeneration systems have been used successfully for many applications. Payback periods vary considerably depending on the local gas and electric rates but tend to be appropriate where the demand charge is high. The following gas turbine-driven system has been selected for its high thermal efficiency, lower emission levels, proven performance, minimum site preparation requirements, lower emission levels, and the availability of the water injection option.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer and Model Number	Caterpillar / Solar Turbines; MARS 100
Rating ISO Base (@ Sea Level, 60 °F, 60% RH)	10,420 kW
Heat Rate (LHV)	**10,681 Btu/kWh**
Fuel Flow (LHV)	111.3 MBtu/Hour
Thermal Efficiency	33.5%
Pressure Ratio	16.0
Turbine Speed	10,780 RPM
Exhaust Gas Temperature	919 °F
Exhaust Gas Flow	327.5 Lb/Hour
NOx Emissions	125 - 140 PPMv (ref 15% O2)
Installed Cost	**800 - 1,000 $/kW (with steam injection)**
O&M Cost	**0.004 $/kWh**
Economic Life	20 Years
Discount Quantity	3 units
Demand Diversity Factor	1.0

Facility Assumptions. It is assumed that, for this application, the gas turbine cogeneration system will operate continuously and provide maximum power. Also assumed is that the DOD installation is large enough that all electricity generated by the cogeneration system is used on base and none is exported to the

utility grid. Normal scheduled maintenance is performed during off-peak periods and full credit for the demand reduction is given for the rated capacity of the cogeneration set. Also a user-selected fraction of the available thermal energy is assumed to be used.

Annual Hours of Operation	8,650
Percent Thermal Recovery	**60%**
Annual Hours for Thermal Recovery	8,650
Boiler Efficiency	70%
Average Capacity of Large Gas Boiler Plant	50 MBtu/hr
Smallest Hospital Area	**30 k sq ft**

Algorithm Modifications. For a detailed discussion of the recommended modifications for this ECO, see Screening/Evaluation of Advanced Gas-Fired Cogeneration Technologies section above. Since it is suggested that multiple sizes of gas turbine-driven cogeneration ECOs be incorporated in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

This ECO algorithm contains "hard coding" of the cogeneration unit size. Because the new ECOs will use the same ECO algorithm, this "hard coding" needs to be remedied. The following relationships show the modifications to the units calculation.

demandcheck = 0.33*xelekwpdem/xassum09v

electcheck = 0.33*xeleserq/(xassum09v/1000)/xassum02v

Also, three other calculations need the "hard coding" of 5000 kW replaced with assumption 9. These are the calculations of baseload demand saved (basdemsav), electric fuel saved (eleenesav), and gas fuel saved (gasenesav).

Because the current version of the REEP program does not allow the input of values with more than six digits to the left of the decimal place, the algorithm multiplied the initial cost (inicos) by 10 to account for this. This limitation will be removed in the next version of the REEP program.

The change to the smallest hospital area (assumption 8) reflects an apparent mismatch between the assumption value (originally 30,000 sq ft) and the units for hospital area in the installation data, which is in thousands of square feet.

U03. Cogeneration - Phosphoric Acid Fuel Cell

Background. Many applications require both electricity and thermal energy. Central energy plants are a prime application at DOD facilities. Cogeneration systems can be sized to meet the thermal load and provide the electricity to the base utility grid. Typical installations would be capable of consuming many MWs of cogenerated electricity without exporting power off the base. The ability of fuel cells to produce electricity in an extremely clean manner (no combustion is involved in its electrochemical process) makes it ideal for situations when reliable backup power is required and in areas where air quality would prevent other power generation technologies from being allowed. At present, the only commercially available fuel cell power plant is a 200 kW phosphoric acid fuel cell. This ECO can operate in parallel with the utility grid or in an independent mode.

ECO Assumptions. Since fuel cells, at current manufacturer-suggested price of $3,000/kW, are only marginally cost effective, the U.S. Government has instituted a rebate program – equivalent to about $1,000/kW – to facilitate this ECO's accelerated deployment in the marketplace. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer and Model Number	United Technologies, Inc.
Rating ISO Base (@ Sea Level, 60 oF, 60% RH)	200 kW
Electric Conversion Efficiency	40%
Installed Cost	**2,000 $/kW (with $1,000/kW rebate)**
O&M Cost	**0.03 $/kWh**
Economic Life	20 Years
Discount Quantity	3 units
Demand Diversity Factor	1.0

Facility Assumptions. It is assumed that this fuel cell will operate at full capacity for 8,320 hours per year (i.e., 95 percent availability), and that the electricity will be used by the DOD facility where it is installed. Full demand credit is taken for the 200 kW demand reduction. It is further assumed that 60 percent of the thermal energy can be used.

Annual Hours of Operation	8,320
Percent Thermal Recovery	**60%**
Annual Hours for Thermal Recovery	8,320
Boiler Efficiency	70%
Average Capacity of Large Gas Boiler Plant	50 MBtu/hr
Smallest Hospital Area	30 k sq ft

Algorithm Modifications. The change to the smallest hospital area (assumption 8) reflects an apparent mismatch between the assumption value (originally 30,000 sq ft) and the units for hospital area in the installation data, which is in thousands of square feet.

U04. Cogeneration - Reciprocating Engine (< 100 kW)

Background. Many applications require both electricity and thermal energy. Central energy plants are a prime application at DOD facilities. Cogeneration systems can be sized to meet the thermal load and provide the electricity to the base utility grid. Typical installations would be capable of consuming many MWs of cogenerated electricity without exporting power off the base. The ability of gas engine generator sets to start quickly and run efficiently makes them ideal for peakshaving applications and in situations where high degree of electrical reliability is required. Smaller size turbine-driven systems (< 3 MW) overlap considerably with engine-driven cogeneration systems.

Gas engine-driven cogeneration systems are available in electrical capacities of a few kWs to several MWs as a single package. Multiple units can be connected in the same system for increased capacity.

Reciprocating gas engine-driven cogeneration systems have been used successfully for many applications. Payback periods vary considerably depending on the local gas and electric rates, but tend to be appropriate where the demand charge is high. In special applications where the added reliability of another source of electricity is required and significant thermal loads exist, such as emergency power for a hospital, a continuously operating cogeneration system can have a near immediate payback. Generally speaking, typical reciprocating gas engine-driven cogeneration systems yield a payback period of less than 3 years.

The following reciprocating gas engine-driven system has been selected for its high thermal efficiency, lower emission levels, proven performance, and minimum site preparation requirements.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above for further explanation of numbers, which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer and Model Number	TECOGEN CM-75
Electrical Power Output	*72 kW*
Heat Rate (LHV)	**12,226 Btu/kWh**
Fuel Flow (LHV)	470,000 Btu/Hour
Combined Efficiency	86.5%
Exhaust Gas Temperature	210 oF
Installed Cost	**1,100 - 1,300 $/kW**
O&M Cost	**0.05 $/kWh**
Economic Life	15 Years
Discount Quantity	3 units
Demand Diversity Factor	1.0

Facility Assumptions. It is assumed that, for this application, the reciprocating gas engine cogeneration system will operate continuously and provide maximum power. Also assumed is that the DOD installation is large enough that all electricity generated by the cogeneration system will be used on base and none will be exported to the utility grid. Normal scheduled maintenance is performed during off-peak periods and full credit for the demand reduction is given for the rated capacity of the cogeneration set. Also a user selected fraction of the available thermal energy is assumed to be used.

Annual Hours of Operation	8,060
Percent Thermal Recovery	**55%**
Annual Hours for Thermal Recovery	8,060
Boiler Efficiency	70%
Average Capacity of Large Gas Boiler Plant	50 MBtu/hr
Smallest Hospital Area	**30 k-sq ft**

Algorithm Modifications. For a detailed discussion of the recommended modifications for this ECO, see the "Screening/Evaluation of Advanced Gas-Fired Cogeneration Technologies" section above. Since it is suggested that multiple sizes of reciprocating gas engine-driven cogeneration ECOs be incorporated in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

This ECO algorithm contains "hard coding" of the cogeneration unit size. Because the new ECOs will use the same ECO algorithm, this "hard coding" needs to be remedied. The following relationships show the modifications to the units calculation.

$$\text{demandcheck} = 0.33 * \text{xelekwpdem}/\text{xassum09v}$$

$$\text{electcheck} = 0.33 * \text{xeleserq}/(\text{xassum09v}/1000)/\text{xassum02v}$$

Also, three other calculations need the "hard coding" of 500 kW replaced with assumption 9. These are the calculations of baseload demand saved (basdemsav), electric fuel saved (eleenesav), and gas fuel saved (gasenesav).

Because the current version of the REEP program does not allow the input of values with more than 6 digits to the left of the decimal place, the algorithm multiplied the initial cost (inicos) by 10 to account for this. It is our understanding that this limitation will be removed in the next version of the REEP program.

The change to the smallest hospital area (assumption 8) reflects an apparent mismatch between the assumption value (originally 30,000 sq ft) and the units for hospital area in the installation data, which is in thousands of square feet.

U05. Cogeneration - Reciprocating Engine (100 to 500 kW)

Background. Many applications require both electricity and thermal energy. Central energy plants are a prime application at DOD facilities. Cogeneration systems can be sized to meet the thermal load and provide the electricity to the base utility grid. Typical installations would be capable of consuming many MWs of cogenerated electricity without exporting power off the base. The ability of gas engine generator sets to start quickly and run efficiently makes them ideal for peakshaving applications and in situations where high degree of electrical reliability is required. Smaller size turbine-driven systems (< 3 MW) overlap considerably with engine-driven cogeneration systems.

Gas engine-driven cogeneration systems are available in electrical capacities of a few kWs to several MWs as a single package. Multiple units can be connected in the same system for increased capacity.

Reciprocating gas engine-driven cogeneration systems have been used successfully for many applications. Payback periods vary considerably depending on the local gas and electric rates, but tend to be appropriate where the demand charge is high. In special applications where the added reliability of another source of electricity is required and significant thermal loads exist, such as emergency power for a hospital, a continuously operating cogeneration system can have a near immediate payback. Generally speaking, typical reciprocating gas engine-driven cogeneration systems yield a payback period of less than 3 years.

The following reciprocating gas engine-driven system has been selected for its high thermal efficiency, lower emission levels, proven performance, and minimum site preparation requirements.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or <u>underlined</u>.)

Manufacturer and Model Number	Caterpillar G3412
Electrical Power Output	*435 kW*
Heat Rate (LHV)	**10,184 Btu/kWh**
Fuel Flow (LHV)	7,600 Btu/hp-Hour (at full load)
Exhaust Gas Stack Temperature	1057 oF
Installed Cost	**130,700 $ (Including heat recovery option)**
O&M Cost	**0.015 $/kWh**
Economic Life	15 Years
Discount Quantity	3 units
Demand Diversity Factor	1.0

Facility Assumptions. It is assumed that, for this application, the reciprocating gas engine cogeneration system will operate continuously and provide maximum power. Also assumed is that the DOD installation is large enough that all electricity generated by the cogeneration system will be used on base and none will be exported to the utility grid. Normal scheduled maintenance is performed during off-peak periods and full credit for the demand reduction is given for the rated capacity of the cogeneration set. Also a user selected fraction of the available thermal energy is assumed to be used.

Annual Hours of Operation	8,160
Percent Thermal Recovery	**58%**
Annual Hours for Thermal Recovery	8,160
Boiler Efficiency	70%
Average Capacity of Large Gas Boiler Plant	50 MBtu/hr
Smallest Hospital Area	**30 k sq ft**

Algorithm Modifications. For a detailed discussion of the recommended modifications for this ECO, see the "Screening/Evaluation of Advanced Gas-Fired Cogeneration Technologies" section above. Since it is suggested that multiple sizes of reciprocating gas engine-driven cogeneration ECOs be incorporated in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

This ECO algorithm contains "hard coding" of the cogeneration unit size. Because the new ECOs will use the same ECO algorithm, this "hard coding" needs to be remedied. The following relationships show the modifications to the units calculation:

demandcheck = 0.33*xelekwpdem/xassum09v
electcheck = 0.33*xeleserq/(xassum09v/1000)/xassum02v

Also, three other calculations need the "hard coding" of 500 kW replaced with assumption 9. These are the calculations of baseload demand saved (basdemsav), electric fuel saved (eleenesav), and gas fuel saved (gasenesav).

Because the current version of the REEP program does not allow the input of values with more than 6 digits to the left of the decimal place, the algorithm multiplied the initial cost (inicos) by 10 to account for this. It is our understanding that this limitation will be removed in the next version of the REEP program.

The change to the smallest hospital area (assumption 8) reflects an apparent mismatch between the assumption value (originally 30,000 sq ft) and the units for hospital area in the installation data, which is in thousands of square feet.

U06. Cogeneration - Reciprocating Engine (500 kW to 2 MW)

Background. Many applications require both electricity and thermal energy. Central energy plants are a prime application at DOD facilities. Cogeneration systems can be sized to meet the thermal load and provide the electricity to the base utility grid. Typical installations would be capable of consuming many MWs of cogenerated electricity without exporting power off the base. The ability of gas engine generator sets to start quickly and run efficiently makes them ideal for peakshaving applications and in situations where high degree of electrical reliability is required. Smaller size turbine-driven systems (< 3 MW) overlap considerably with engine-driven cogeneration systems.

Gas engine-driven cogeneration systems are available in electrical capacities of a few kWs to several MWs as a single package. Multiple units can be connected in the same system for increased capacity.

Reciprocating gas engine-driven cogeneration systems have been used successfully for many applications. Payback periods vary considerably depending on the local gas and electric rates, but tend to be appropriate where

the demand charge is high. In special applications where the added reliability of another source of electricity is required and significant thermal loads exist, such as emergency power for a hospital, a continuously operating cogeneration system can have a near immediate payback. Generally speaking, typical reciprocating gas engine-driven cogeneration systems yield a payback period of less than 3 years. The following reciprocating gas engine-driven system has been selected for its high thermal efficiency, lower emission levels, proven performance, and minimum site preparation requirements.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer and Model Number	Waukesha Power Systems VHP9500GL
Electrical Power Output	*1,475 kW*
Heat Rate (LHV)	**10,161 Btu/kWh**
Exhaust Gas Stack Temperature	761 oF
Installed Cost	**1,106,250 $**
O&M Cost	**0.0165 $/kWh**
Economic Life	15 Years
Discount Quantity	3 units
Demand Diversity Factor	1.0

Facility Assumptions. It is assumed that, for this application, the reciprocating gas engine cogeneration system will operate continuously and provide maximum power. Also assumed is that the DOD installation is large enough that all electricity generated by the cogeneration system is used on base and none is exported to the utility grid. Normal scheduled maintenance is performed during off-peak periods and full credit for the demand reduction is given for the rated capacity of the cogeneration set. Also, a user-selected fraction of the available thermal energy is assumed.

Annual Hours of Operation	8,232
Percent Thermal Recovery	**52%**
Annual Hours for Thermal Recovery	8,232
Boiler Efficiency	70%
Average Capacity of Large Gas Boiler Plant	50 MBtu/hr
Smallest Hospital Area	**30 k-sq ft**

Algorithm Modifications. For a detailed discussion of the recommended modifications for this ECO, see the "Screening/Evaluation of Advanced Gas-Fired Cogeneration Technologies" section above. Since it is suggested that multiple sizes of reciprocating gas engine-driven cogeneration ECOs be incorporated in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

This ECO algorithm contains "hard coding" of the cogeneration unit size. Because the new ECOs will use the same ECO algorithm, this "hard coding" needs to be remedied. The following relationships show the modifications to the units calculation.

demandcheck = 0.33*xelekwpdem/xassum09v
electcheck = 0.33*xeleserq/(xassum09v/1000)/xassum02v

Also, three other calculations need the "hard coding" of 500 kW replaced with assumption 9. These are the calculations of baseload demand saved (basdemsav), electric fuel saved (eleenesav), and gas fuel saved (gasenesav).

Because the current version of the REEP program does not allow the input of values with more than 6 digits to the left of the decimal place, the algorithm multiplied the initial cost (inicos) by 10 to account for this. This limitation will be removed in the next version of the REEP program.

The change to the smallest hospital area (assumption 8) reflects an apparent mismatch between the assumption value (originally 30,000 sq ft) and the units for hospital area in the installation data, which is in thousands of square feet.

U07. Cogeneration - Reciprocating Engine (> 2 MW)

Background. Many applications require both electricity and thermal energy. Central energy plants are a prime application at DOD facilities. Cogeneration systems can be sized to meet the thermal load and provide the electricity to the base utility grid. Typical installations would be capable of consuming many MWs of cogenerated electricity without exporting power off the base. The ability of gas engine generator sets to start quickly and run efficiently makes them ideal for peakshaving applications and in situations where high degree of electrical reliability is required. Smaller size turbine-driven systems (< 3 MW) overlap considerably with engine-driven cogeneration systems.

Gas engine-driven cogeneration systems are available in electrical capacities of a few kWs to several MWs as a single package. Multiple units can be connected in the same system for increased capacity.

Reciprocating gas engine-driven cogeneration systems have been used successfully for many applications. Payback periods vary considerably depending on the local gas and electric rates but tend to be appropriate where the demand charge is high. In special applications where the added reliability of

another source of electricity is required and significant thermal loads exist, such as emergency power for a hospital, a continuously operating cogeneration system can have a near immediate payback. Generally speaking, typical reciprocating gas engine-driven cogeneration systems yield a payback period of less than 3 years. The following reciprocating gas engine-driven system has been selected for its high thermal efficiency, lower emission levels, proven performance, and minimum site preparation requirements.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer and Model Number	Caterpillar G3616
Electrical Power Output	*3,049 kW*
Heat Rate (LHV)	**8,811 Btu/kWh**
Fuel Flow (LHV)	6,575 Btu/hp-Hour (at full load)
Exhaust Gas Stack Temperature	810 oF
Installed Cost	**1,660,000 $**
O&M Cost	**0.015 $/kWh**
Economic Life	15 Years
Discount Quantity	3 units
Demand Diversity Factor	1.0

Facility Assumptions. It is assumed that, for this application, the reciprocating gas engine cogeneration system will operate continuously and provide maximum power. Also assumed is that the DOD installation is large enough that all electricity generated by the cogeneration system is used on base and none is exported to the utility grid. Normal scheduled maintenance is performed during off-peak periods and full credit for the demand reduction is given for the rated capacity of the cogeneration set. Also a user selected fraction of the available thermal energy is assumed to be used.

Annual Hours of Operation	8,320
Percent Thermal Recovery	**52%**
Annual Hours for Thermal Recovery	8,320
Boiler Efficiency	70%
Average Capacity of Large Gas Boiler Plant	50 MBtu/hr
Smallest Hospital Area	**30 k sq ft**

Algorithm Modifications. For a detailed discussion of the recommended modifications for this ECO, see the "Screening/Evaluation of Advanced Gas-Fired Cogeneration Technologies" section above. Since it is suggested that multiple sizes of reciprocating gas engine-driven cogeneration ECOs be incorporated in the revised version of the REEP program, the "percent locations applicable" assumption may have to be changed.

This ECO algorithm contains "hard coding" of the cogeneration unit size. Because the new ECOs will use the same ECO algorithm, this "hard coding" needs to be remedied. The following relationships show the modifications to the units calculation:

demandcheck = 0.33*xelekwpdem/xassum09v
electcheck = 0.33*xeleserq/(xassum09v/1000)/xassum02v

Also, three other calculations need the "hard coding" of 500 kW replaced with assumption 9. These are the calculations of baseload demand saved (basdemsav), electric fuel saved (eleenesav), and gas fuel saved (gasenesav).

Because the current version of the REEP program does not allow the input of values with more than 6 digits to the left of the decimal place, the algorithm multiplied the initial cost (inicos) by 10 to account for this. This limitation will be removed in the next version of the REEP program.

The change to the smallest hospital area (assumption 8) reflects an apparent mismatch between the assumption value (originally 30,000 sq ft) and the units for hospital area in the installation data, which is in thousands of square feet.

U08. Direct-Fired Gas Absorption Chiller (<5 RT)

Background. Absorption chillers use direct heat to boil a refrigerant from a solution rather than using a compressor. Some advantages over conventional equipment are: fewer moving parts, no CFCs or HFCs, electrical demand savings, and lower operating pressures. This technology also provides a summer load for the gas system, and may allow users to benefit from financial incentives from the local utility. It also provides 80 percent effective winter heating. Four different size ranges of chillers are considered: <5 RT, 5 - 25 RT, 25-100 RT, and > 100 RT. It is assumed that they always replace older, electric motor chiller systems. They should be considered replacing the gas furnace/electric air conditioner in <5 RT category.

Robur Corporation's research and development department received American Gas Association Design Certification for its new, more efficient direct-fired air-cooled 5-ton chiller in December 1995. The new series of equipment is an environment friendly ammonia/water refrigerant/absorbent system with no CFCs or HCFCs. The individual unit as well as the 10-, 15-, 20-, and 25-ton packaged systems required no cooling towers and only single-phase power. Commercialization and market introduction of the new chiller line, with a

steady-state COP of 0.62, is expected in late 1997 or early 1998. The initial equipment offering will include a 5-ton unit that allows modular staged, packages systems up to 25-ton capacities. This commercial-grade equipment is ideal for large custom residential and light-commercial comfort cooling as well as industrial process cooling applications.

These units are similar to GAX cycle machines. Their costs should remain comparable to the basic line of SERVEL's chillers, yet they were demonstrated to operate with much higher COP. They are air-cooled; no cooling towers or water treatment maintenance is needed; modular systems can be staged in 5-ton increments; adapts to changing load conditions automatically.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	**Robur Corp.**	
Type/Brand Name	AYE 36 - 110/Servelsm Chiller/Heater	
Size of Replacement Unit	**3**	**RT**
Gas Usage	**19,333**	**BTU/RT-hr**
Cooling Temperature/Delivered Water Temp.	78	°F
Gas Chiller Electrical Usage	**0.25**	**kW/RT**
Replaced Chiller Electrical Usage	1.25	kW/RT
Installed Cost Per Unit	**6,000**	**$**
Recurring Cost	1	percent of capital cost
Water Usage over Replaced Chiller	None	
Penetration Factor	40	%
Demand Diversity factor	0.8	
Increased Recurring costs (% of CC)	1.0	%
HCFCs Avoided	2.2	lb/RT
Discount Quantity	10	units
Economic life	20	years

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. The energy usage and savings calculations for direct-fired chiller ECO algorithms are modified to use an average cooling season temperature differential rather than the difference between the design temperature and the indoor temperature. Using the design temperature could

overstate the electric energy saved and the gas energy consumed. These modifications may still be less than ideal. (For further details, please refer to Appendix B, "Discussion On Cooling Season-Related Data in REEP").

$$\text{Electric Energy Saved} = 24 \frac{\text{CDD}}{\frac{\text{CDD}}{\text{D}_\text{C}} - (\text{A}_2 - 65)} \text{SDS} \times \frac{3412}{10^6}$$

where:

A_2 = assumption 2 (cooling temp)

SDS = the Summer Demand Saved (earlier calculation)

3412 = the conversion from kW to Btu/hr

$$\text{Gas Energy Saved} = -24 \frac{\text{CDD}}{\frac{\text{CDD}}{\text{D}_\text{C}} - (\text{A}_2 - 65)} \text{A}_1 \times \text{Units} \frac{\text{A}_3}{10^6} \text{A}_8$$

where:

A_x = assumption X (1: unit size (RT), 3: Unit gas usage (Btu/RT), 8: Demand diversity)

DC = the cooling season days.

This is a new chiller size and requires a new ECO algorithm similar to the current ECO algorithm for direct-fired chillers greater than 100 tons. The new algorithm should include the following modified relationship for units calculation:

$$numecouni = (1 - penfac) * \mathbf{xacw5cap} / xassum01v$$

where:

xacw5cap = the A/C and chilled water plant < 5 tons capacity

xassum01v = the value for assumption 1.

For commercial installations, the number of chillers replaced is calculated by dividing the installation's total cooling capacity in the respective range by an

assumed chiller size. Electrical savings and the gas cost increase are then determined based on the assumptions above. Economic benefit with respect to HCFC replacement has not been calculated; however, the number of pounds displaced is included in the results. The chillers in the 3-50 RT range are assumed to be air-cooled.

The residential gas fired chiller/heater algorithm bases energy savings on the difference in energy consumption between the old and the new unit, multiplied by the number of hours the unit would run annually. The number of hours an A/C system operates is a function of climate. The differences in the energy consumption are due to the high efficiency of the gas fired chiller/heater.

Sources. Direct Contact With Manufacturers; Natural Gas Cooling Equipment Guide, 4th ed., April 1996.

U09. Direct-Fired Gas Absorption Chiller (5 to 25 RT)

Background. Absorption chillers use direct heat to boil a refrigerant from a solution rather than using a compressor. Some advantages over conventional equipment are: fewer moving parts, no CFCs or HFCs, electrical demand savings, and lower operating pressures. This technology also provides a summer load for the gas system, and may allow users to benefit from financial incentives from the local utility. It also provides 80 percent effective winter heating. Four different size ranges of chillers are considered: <5 RT, 5-25 RT, 25-100 RT, and >100 RT. It is assumed that they always replace older, electric motor chiller systems.

This ECO represents a broad line of double-effect, high efficiency absorption chiller/heaters. It can supply both chilled and hot water to meet building requirements. Other important features of the selected ECO include: automated high-performance purge unit that eliminates daily operator purging; modular design for easy retrofit where space consideration is a priority; cabinet suited to outdoor installation; automatic crystallization control to prevent nuisance shutdown; factory-mounted burner, factory-charged and tested unit allow for quick start-up; factory-trained service through nationwide service organization; and an environmentally friendly inhibitor that uses no chromates or nitrates.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the

Notation Conventions section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	McQuay International	
Type/Brand Name	ME-21E/Modular Chiller/Heater	
%5-25 RT Chillers in 5-100 RT Range	35	%
Size of Replacement Unit	**20**	**RT**
Gas Usage	**12,631**	**Btu/RT-hr**
Cooling Temperature/Delivered Water Temp.	78	°F
Gas Chiller Electrical Usage	**0.26**	**kW/RT**
Replaced Chiller Electrical Usage	1.25	kW/RT
Installed Cost per Unit	**27,500**	**$**
Water Usage over Replaced Chiller	2.2	gal/RT-hrs
Penetration Factor	40	%
Demand Diversity Factor	0.8	
Increased Recurring costs (% of CC)	1.0	%
CFCs Avoided	2.2	lbs/RT
Discount Quantity	10	units
Economic life	20	years

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. The energy usage and savings calculations for direct-fired chiller ECO algorithms are modified to use an average cooling season temperature differential rather than the difference between the design temperature and the indoor temperature. Using the design temperature could overstate the electric energy saved and the gas energy consumed. These modifications may still be less than ideal (for further details, please refer to Appendix B, "Discussion On Cooling Season-Related Data in REEP").

$$\text{Electric Energy Saved} = 24 \frac{CDD}{\frac{CDD}{D_C} - (A_2 - 65)} SDS \times \frac{3412}{10^6}$$

where:

A_2 = assumption 2 (cooling temp),

SDS = the Summer Demand Saved (earlier calculation), and

3412 = the conversion from kW to Btu/hr.

$$\text{Gas Energy Saved} = -24 \frac{CDD}{\frac{CDD}{D_C} - (A_2 - 65)} A_1 \times \text{Units} \frac{A_3}{10^6} A_8$$

where:

A_x = assumption X (1: unit size (RT), 3: Unit gas usage (Btu/RT), 8: Demand diversity)

D_c = the cooling season days

There remain three size categories of utility-class absorption chillers (i.e., > 5 tons), but it is recommended that the size boundaries be modified. The existing boundaries are 5, 50, and 100 tons. The 50 ton boundary should be reduced to 25 tons. Because of the recommended change in boundary Assumption 9 (percent of chillers between 5 and 100 tons) needs to reflect the new boundary.

The number of chillers replaced is calculated by dividing the installations' total cooling capacity in the respective range by an assumed chiller size. Electrical savings and the gas cost increase are then determined based on the assumptions above. Economic benefit with respect to CFC replacement has not been calculated. However, the number of pounds displaced is included in the results. The more likely reference in these calculations is to HCFC since these would be commonly used in electric chillers.

The chillers in this size range are assumed to be air-cooled. However, this unit is water cooled.

The "Replaced Chiller Electrical Usage" of 1.25 kW/RT is rather high. For older units, values closer to about 1.0 kW/RT would be more likely; for new units they are close to 0.6 kW/RT.

Sources. Direct Contact With Manufacturers; Natural Gas Cooling Equipment Guide, 4th ed., April 1996.

U10. Direct-Fired Gas Absorption Chiller (25 to 100 RT)

Background. Absorption chillers use direct heat to boil a refrigerant from a solution rather than using a compressor. Some advantages over conventional equipment are: fewer moving parts, no CFCs or HFCs, electrical demand savings and lower operating pressures. Using this technology also provides a summer load for the gas system, and may allow users to benefit from financial incentives from the local utility. It also provides 80 percent effective winter heating. Four different size ranges of chillers are considered: <5 RT, 5-25 RT, 25-100 RT, and >100 RT. It is assumed that they always replace older, electric motor chiller systems.

This ECO represents one of the six Yazaki V-Series Chiller/Heaters available in this size range. It is designed for commercial applications where chilled and hot water are used in a central air conditioning system. The selected ECO shows improved performance from a double-effect absorption cycle and efficient forced draft gas burner reduces fuel consumption by up to 40 percent compared with single-effect absorption chillers. This unit offers slightly better performance in heating and cooling compared to those of McQuay.

Other important features for the selected ECO include: single unit that provides both cooling and heating; burner efficiency of 83 percent; automatic step control to increase part-load performance; built-in control panel with microprocessor controls that simplifies installations and maintenance; a standard weatherproof cabinet that makes units suitable for outdoor installations; shutdown controls built in for abnormal cooling water conditions; and modular construction for ease in transportation, lifting, and handling.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	American Yazaki Corp.	
Type/Brand Name	CH-V50/V-Series Chiller/Heater	
%25-100 RT Chillers in 5-100 RT Range	65	%
Size of Replacement Unit	**50**	**RT**
Gas Usage	**12,631**	**Btu/RT-hr**
Cooling Temperature/Delivered Water Temp.	78	°F
Gas Chiller Electrical Usage	**0.26**	**kW/RT**
Replaced Chiller Electrical Usage	1.25	kW/RT
Installed Cost per Unit	**85,000**	**$**
Water Usage over Replaced Chiller	2.2	gal/RT-hr
Penetration Factor	40	%
Demand Diversity Factor	0.8	
Recurring cost	1.0	% of capital cost/year
CFCs Avoided	2.2	lbs/RT
Discount Quantity	5	units
Economic life	20	years

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. The energy usage and savings calculations for direct-fired chiller ECO algorithms are modified to use an average cooling season temperature differential rather than the difference between the design

temperature and the indoor temperature. Using the design temperature could overstate the electric energy saved and the gas energy consumed. These modifications may still be less than ideal. (For further details, please refer to Appendix B, "Discussion On Cooling Season-Related Data in REEP.")

$$\text{Electric Energy Saved} = 24 \frac{\text{CDD}}{\frac{\text{CDD}}{D_C} - (A_2 - 65)} \text{SDS} \times \frac{3412}{10^6}$$

where:

A_2 = assumption 2 (cooling temp)

SDS = the Summer Demand Saved (earlier calculation)

3412 = the conversion from kW to Btu/hr.

$$\text{Gas Energy Saved} = -24 \frac{\text{CDD}}{\frac{\text{CDD}}{D_C} - (A_2 - 65)} A_1 \times \text{Units} \frac{A_3}{10^6} A_8$$

where:

AX = assumption X (1: unit size (RT), 3: Unit gas usage (Btu/RT), 8: Demand diversity), and

DC = the cooling season days.

There remain three size categories of utility-class absorption chillers (i.e., > 5 tons), but it is recommended that the size boundaries be modified. The existing boundaries are 5, 50, and 100 tons. The 50 ton boundary should be reduced to 25 tons. Because of the recommended change in boundary Assumption 9 (percent of chillers between 5 and 100 tons) needs to reflect the new boundary.

The number of chillers replaced is calculated by dividing the installations' total cooling capacity in the respective range by an assumed chiller size. Electrical savings and the gas cost increase are then determined based on the assumptions above. Economic benefit with respect to CFC replacement has not been calculated; however the number of pounds displaced is included in the results. The more likely reference in these calculations is to HCFC since these would be commonly used in electric chillers.

The chillers in this size range are assumed to be air-cooled; however this unit is water cooled.

The "Replaced Chiller Electrical Usage" of 1.25 kW/RT is rather high. For older units, values closer to about 1.0 kW/RT would be more likely, for new units they are close to 0.6 kW/RT.

Sources. Direct Contact With Manufacturers; Natural Gas Cooling Equipment Guide, 4th ed., April 1996.

U11. Direct-Fired Gas Absorption Chiller (> 100 RT)

Background. Absorption chillers use direct heat to boil a refrigerant from a solution rather than using a compressor. Some advantages over conventional equipment are: fewer moving parts, no CFCs or HFCs, electrical demand savings and lower operating pressures. Using this technology also provides summer load for the gas system and may benefit from financial incentives from the local utility. It also provides 80 percent effective winter heating. Four different size ranges of chillers are considered: <5 RT, 5-25 RT, 25-100 RT, and >100 RT. It is assumed that they always replace older, electric motor chiller systems.

Dunham-Bush introduced Iron-Fireman® Direct-Fired Double-Effect Absorption Chillers into American markets. The units are manufactured to Dunham-Bush specifications by Thermax Ltd., at its ISO 9002-certified facility in India. Thermax has more than 600 successful absorption chiller applications operating throughout the world. Iron-Fireman® absorption chillers provide reliable and environmentally friendly operation. The units offer low life-cycle cost and low maintenance. Consisting of a shell-and-tube heat exchanger, the chillers use a lithium bromide-water cycle driven by a natural gas-fueled heat source. They produce chilled water that can be used in fan coil units or air handling units for comfort cooling or in heat exchangers for process cooling. Iron-Fireman® absorption chillers are controlled by a Dunham-Bush microcomputer and feature Iron-Fireman® burners.

These units, produced in sizes of 240, 260, and 550 RT are regarded as well performing yet lowest cost equipment on the market. They offer microcomputer control, chilled water down to 40.1 °F, dual fuel capability, and rooftop installations as an option.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	Dunham-Bush, Inc.	
Type/Brand Name	WCGA-240/Iron Fireman®	
Size of Replacement Unit	**240**	**RT**
Gas Usage	**12,631**	**Btu/RT-hr**
Cooling Temperature/Delivered Water Temp.	78	°F
Gas Chiller Electrical Usage	**0.26**	**kW/RT**
Replaced Chiller Electrical Usage	1.25	kW/RT
Installed Cost per Unit	**190,000**	**$**
Water Usage over Replaced Chiller	2.2	gal/RT-hr
Penetration Factor	40	%
Demand Diversity Factor	0.8	
Recurring cost	1.0	% of capital cost/year
CFCs Avoided	2.2	lb/RT
Discount Quantity	5	units
Economic life	20	years
% Chillers Between 5-100 RT	N/A	

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. The energy usage and savings calculations for direct-fired chiller ECO algorithms are modified to use an average cooling season temperature differential rather than the difference between the design temperature and the indoor temperature. Using the design temperature could overstate the electric energy saved and the gas energy consumed. These modifications may still be less than ideal. (For further details, please refer to Appendix B, "Discussion On Cooling Season-Related Data in REEP.")

$$\text{Electric Energy Saved} = 24 \frac{CDD}{\frac{CDD}{D_C} - (A_2 - 65)} SDS \times \frac{3412}{10^6}$$

where:

A_2 = assumption 2 (cooling temp)

SDS = the Summer Demand Saved (earlier calculation)

3412 = the conversion from kW to Btu/hr.

$$\text{Gas Energy Saved} = -24 \frac{CDD}{\frac{CDD}{D_C} - (A_2 - 65)} A_1 \times \text{Units} \frac{A_3}{10^6} A_8$$

where:

A_x = assumption X (1: unit size (RT), 3: Unit gas usage (Btu/RT), 8: Demand diversity)

D_c = the cooling season days.

There remain three size categories of utility-class absorption chillers (i.e., > 5 tons), but it is recommended that the size boundaries be modified. The existing boundaries are 5, 50, and 100 tons. The 50 ton boundary should be reduced to 25 tons. Because of the recommended change in boundary Assumption 9 (percent of chillers between 5 and 100 tons) needs to reflect the new boundary.

The number of chillers replaced is calculated by dividing the installations' total cooling capacity in the respective range by an assumed chiller size. Electrical savings and the gas cost increase are then determined based on the assumptions above. Economic benefit with respect to CFC replacement has not been calculated; however the number of pounds displaced is included in the results. The more likely reference in these calculations is to HCFC since these would be commonly used in electric chillers.

The chillers in this size range are assumed to be air-cooled. However this unit is water cooled.

The "Replaced Chiller Electrical Usage" of 1.25 kW/RT is rather high. For older units, values closer to about 1.0 kW/RT would be more likely, for new units they are close to 0.6 kW/RT.

Sources. Direct Contact With Manufacturers; Natural Gas Cooling Equipment Guide, 4th ed., April 1996.

U12. Gas Engine-Driven Air Compressor

Background. Industrial air compressors range in size from very small to several hundred hp. Air compressors typically use electric motors as their prime mover. These compressors operate on an as required basis and can add significantly to an installation's peak electrical demand. Typically only a portion of these compressors would be converted to natural gas engine driven prime movers. Additional controls would provide an operating sequence such that during the on-peak period, the engine driven air compressors are the lead system

while the electrically driven compressors lag. This allows for the greatest possible demand reduction.

Engine-driven products of this type are type are rather effective particularly when heat recovery from the engine could be considered for (for example) hot water applications. It should also be remembered that, for a cost premium, a variable speed operation would boost the system efficiency by about 25 percent. This option would be very useful since most of the installation operate between 60 and 70 percent load range. Other desirable features of the gas versions are: a balance of the electrical/gas utilities; better fuel costs and reliability; and the ability to free up capacity of electric substations.

ECO Assumptions. Engine driven air compressors are available in a large range of 30 to 4000 horsepower and about 20 to 2500 cfm (at 110 and 125 psig) capacities. Added engine maintenance costs are included at $0.01/hp-hr. This will cover the recurring maintenance costs along with engine rebuilds as required. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer	Dearing Gas Engine Products Group	
Type/Brand Name	Ultra-Air™ GRS - 300L	
Unit Capacity	1,500	cfm
Installed Cost	**168,000**	**$ (with catalytic converter)**
Recurring Cost	**17**	**% of capital cost/year**
Economic Life	10	years
Discount Quantity	1	unit
Unit Gas Consumption	**2,908**	**Btu/hp-hr**
Water Consumption (@85 °F)	125	gpm
Engine Size	*1,000*	*hp*
Increased Water Usage	*50*	*gpm*
Replaced Motor Efficiency	0.9	
Annual Hours of Operation	2,719	hours

Facility Assumptions. Air compressors cycle on and off throughout the day to meet the changing compressed air demands of the industrial facility. This ECO assumes that proper controls are installed so that the full amount of the displaced electric power of the replaced pumps can be taken as an electric demand credit.

Algorithm Modifications. Minor modifications to the ECO algorithm are recommended to take into account the size of the engine/compressor package as well as increased water usage. The units calculation should reflect the size of

the package. Because the old ECO algorithm "hard coded" a 100 hp package, the new calculation is referenced to that size.

$$numecouni = (1 - penfac) * xmaiproare/1000 * \mathbf{100/xassum05v}$$

Three other calculations need the "hard coding" of 100 hp replaced with assumption 5. These are the calculations of baseload demand saved (basdemsav), electric fuel saved (eleenesav), and gas fuel saved (gasenesav). Finally, water usage and cost calculations should be added as follows:

$$watvolsav = -1 * xassum06v * 60 * xassum03v/1000$$

$$watcossav = watvolsav * xwatseru$$

Source. Direct communication with manufacturer.

U13. Gas Engine-Driven Chiller (5 to 25 RT).

Background. A gas engine-driven chiller uses the same cooling process as a conventional electric-powered system except the electric motor is replaced by a gas engine. The engine provides variable-speed operation, higher part-load efficiency, and waste-heat recovery. Switching to natural gas from electricity can reduce summer peak electrical demand, and provides a summer gas load that may bring financial incentives from the local natural gas utility. This analysis does not consider the benefits of waste-heat recovery for domestic hot water use or steam generation. Three different size ranges of gas engine-driven chillers are considered: 5-25 RT, 25-100 RT, and >100 RT. It is assumed that they always replace older, electric motor chiller systems.

This technology provides air-cooled, unitary packages, with direct replacement possibility and ease of installation. It features advanced engines (GM power packs) and compressors (Bitzer) while preserving low cost and high reliability. Installations are under single manufacturer warranty. Other important features for this ECO include lower installation cost and shorter installation time; increased maintainability; low noise operation (optional feature); and the availability of units as either liquid chillers or D-X units.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or <u>underlined</u>.)

Manufacturer	GASAIR, Inc.	
Type/Brand Name	ARW-20	
% Chillers Between 5 to 100 tons	35	%
Size of Replacement Unit	**20**	**RT**
Gas Usage	**12,250**	**Btu/RT**
Cooling Temperature	78	°F
Gas Chiller Electrical Usage	**0.05**	**kW/RT**
Increased Water usage	**0.0**	**gallons/ton-hours**
Replaced Chiller Electrical Usage	1.25	kW/RT
Installed Cost per Unit	**32,500**	**$**
Penetration Factor	40	%
Recurring Costs	**2.5**	**% of capital cost/year**
CFC's Avoided	0	lbs/RT
Discount Quantity	10	units
Economic Life	**10**	**years**
Demand Diversity Factor	0.8	

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. The energy usage and savings calculations for gas engine-driven chiller ECO algorithms are modified to use an average cooling season temperature differential rather than the difference between the design temperature and the indoor temperature. Using the design temperature could overstate the electric energy saved and the gas energy consumed. These modifications may still be less than ideal (for further details, please refer to Appendix B, "Discussion On Cooling Season-Related Data in REEP").

$$\text{Electric Energy Saved} = 24\frac{CDD}{\frac{CDD}{D_C} - (A_2 - 65)} SDS \times \frac{3412}{10^6}$$

where:

A_2 = assumption 2 (cooling temp)

SDS = the Summer Demand Saved (earlier calculation)

3412 = the conversion from kW to Btu/hr.

$$\text{Gas Energy Saved} = -24\frac{CDD}{\frac{CDD}{D_C} - (A_2 - 65)} A_1 \times \text{Units}\frac{A_3}{10^6} A_8$$

where:

A_x = assumption X (1: unit size (RT), 3: Unit gas usage (Btu/RT), 8: Demand diversity)

D_c = the cooling season days

There remain three size categories of utility-class engine-driven chillers (i.e., > 5 tons), but it is recommended that the size boundaries be modified. The existing boundaries are 5, 50, and 100 tons. The 50 ton boundary should be reduced to 25 tons. Because of the recommended change in boundary Assumption 9 (% chillers between 5 and 100 tons) needs to reflect the new boundary.

The number of chillers replaced is calculated by dividing the installations' total cooling capacity in the respective range by and assumed chiller size. Electrical savings and the gas cost increase are then determined based on the assumptions above. Economic benefit with respect to CFC replacement has not been calculated. However the number of pounds displaced is included in the results. The more likely reference in these calculations is to HCFC since these would be commonly used in electric chillers. The chillers in this size range are assumed to be air-cooled.

Discount quantity value is negotiable. Currently, no discounts were practiced since no larger numbers are being sold to a single customer. Economic life given is meant as time to major engine overhaul. The rest of the system has much longer economic life.

Sources. Direct Contact With Manufacturers; Natural Gas Cooling Equipment Guide, 4th ed., April 1996.

U14. Gas Engine-Driven Chiller (25 to 100 RT)

Background. A gas engine-driven chiller uses the same cooling process as a conventional electric-powered system except the electric motor is replaced by a gas engine. The engine provides variable-speed operation, higher part-load efficiency, and waste-heat recovery. Switching to natural gas from electricity can reduce summer peak electrical demand, and provides a summer gas load that may bring financial incentives from the local natural gas utility. This analysis does not consider the benefits of waste-heat recovery for domestic hot water use or steam generation. Three different size ranges of gas engine-driven chillers are considered: 5-25 RT, 25-100 RT, and >100 RT. It is assumed that they always replace older, electric motor chiller systems.

This technology provides air-cooled, unitary packages, with direct replacement possibility and easy installation. It features advanced engines (GM power packs) and compressors (Bitzer) while preserving low cost and high reliability. Installations are under single manufacturer warranty. Other important features

for this ECO include lower installation cost and shorter installation time; increased maintainability; and low noise operation (optional feature).

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the Notation Conventions section above for further explanation of numbers in italics, boldface, and/or underlined.)

Manufacturer	GASAIR, Inc.	
Type/Brand Name	ARW-80	
% Chillers Between 5 to 100 tons	65	%
Size of Replacement Unit	**80**	**RT**
Gas Usage	**11,111**	**Btu/RT**
Cooling Temperature	78	°F
Gas Chiller Electrical Usage	**0.05**	**kW/RT**
Increased Water usage	**0.0**	**gallons/ton-hours**
Replaced Chiller Electrical Usage	1.25	kW/RT
Installed Cost per Unit	**110,000**	**$**
Penetration Factor	40	%
Recurring Costs	**2.5**	**% of capital cost/year**
CFC's Avoided	0	lbs/RT
Discount Quantity	5	units
Economic Life	**10**	**years**
Demand Diversity Factor	0.8	

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. The energy usage and savings calculations for gas engine-driven chiller ECO algorithms are modified to use an average cooling season temperature differential rather than the difference between the design temperature and the indoor temperature. Using the design temperature could overstate the electric energy saved and the gas energy consumed. These modifications may still be less than ideal. (For further details, please refer to Appendix B, "Discussion On Cooling Season-Related Data in REEP.")

$$\text{Electric Energy Saved} = 24 \frac{CDD}{\frac{CDD}{D_C} - (A_2 - 65)} SDS \times \frac{3412}{10^6}$$

where:

A_2 = assumption 2 (cooling temp)

SDS = the Summer Demand Saved (earlier calculation)

3412 = the conversion from kW to Btu/hr

$$\text{Gas Energy Saved} = -24 \frac{CDD}{\frac{CDD}{D_C} - (A_2 - 65)} A_1 \times \text{Units} \frac{A_3}{10^6} A_8$$

where:

A_x = assumption X (1: unit size (RT), 3: Unit gas usage (Btu/RT), 8: Demand diversity)

D_c = the cooling season days.

There remain three size categories of utility-class engine-driven chillers (i.e., > 5 tons), but it is recommended that the size boundaries be modified. The existing boundaries are 5, 50, and 100 tons. The 50 ton boundary should be reduced to 25 tons. Because of the recommended change in boundary, Assumption 9 (percent of chillers between 5 and 100 tons) needs to reflect the new boundary.

The number of chillers replaced is calculated by dividing the installations' total cooling capacity in the respective range by and assumed chiller size. Electrical savings and the gas cost increase are then determined based on the assumptions above. Economic benefit with respect to CFC replacement has not been calculated. However the number of pounds displaced is included in the results. The more likely reference in these calculations is to HCFC since these would be commonly used in electric chillers. The chillers in this size range are assumed to be air-cooled.

Discount quantity value is negotiable. Currently, no discounts were practiced since no larger numbers are being sold to a single customer. Economic life given is meant as time to major engine overhaul. The rest of the system has much longer economic life.

Sources. Direct Contact With Manufacturers; Natural Gas Cooling Equipment Guide, 4th ed., April 1996.

U15. Gas Engine-Driven Chiller (> 100 RT)

Background. A gas engine-driven chiller uses the same cooling process as a conventional electric-powered system except the electric motor is replaced by a gas engine. The engine provides variable-speed operation, higher part-load efficiency, and waste-heat recovery. Switching to natural gas from electricity can reduce summer peak electrical demand, and provide a summer gas load that may bring financial incentives from the local natural gas utility. This analysis

does not consider the benefits of waste-heat recovery for domestic hot water use or steam generation. Three different size ranges of gas engine-driven chillers are considered: 5-25 RT, 25-100 RT, and >100 RT. It is assumed that they always replace older, electric motor chiller systems.

This technology provides air-cooled, unitary packages, with direct replacement possibility and ease of installation. It features advanced engines (Cummins) and compressors (Royce) with higher efficiencies while preserving low cost and high reliability. Installations are under single manufacturer warranty. It is considered as advantageous to assume all the engine driven chillers to be supplied by one company, in this case GASAIR.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the Notation Conventions section above for further explanation of numbers in italics, boldface, and/or underlined.)

Manufacturer	GASAIR, Inc.	
Type/Brand Name	ARW-80	
<u>% Chillers Between 5 to 100 tons</u>	<u>N/A</u>	
Size of Replacement Unit	**170**	**RT**
Gas Usage	**10,400**	**Btu/RT**
Cooling Temperature	78	°F
Gas Chiller Electrical Usage	**0.05**	**kW/RT**
Increased Water usage	**0.0**	**gallons/ton-hours**
Replaced Chiller Electrical Usage	1.25	kW/RT
Installed Cost per Unit	**210,000**	**$**
Penetration Factor	40	%
Recurring Costs	**2.5**	**% of capital cost/year**
CFC's Avoided	0	lbs/RT
Discount Quantity	5	units
Economic Life	**10**	**years**
Demand Diversity Factor	0.8	

Facility Assumptions. All facility assumptions for this ECO remain unchanged from those currently in REEP.

Algorithm Modifications. The energy usage and savings calculations for gas engine-driven chiller ECO algorithms are modified to use an average cooling season temperature differential rather than the difference between the design temperature and the indoor temperature. Using the design temperature could overstate the electric energy saved and the gas energy consumed. These modifications may still be less than ideal. (For further details, please refer to Appendix B, "Discussion On Cooling Season-Related Data in REEP.")

$$\text{Electric Energy Saved} = 24\frac{CDD}{\frac{CDD}{D_C}-(A_2-65)}SDS \times \frac{3412}{10^6}$$

where:

A_2 = assumption 2 (cooling temp)

SDS = the Summer Demand Saved (earlier calculation)

3412 = the conversion from kW to Btu/hr

$$\text{Gas Energy Saved} = -24\frac{CDD}{\frac{CDD}{D_C}-(A_2-65)}A_1 \times \text{Units}\frac{A_3}{10^6}A_8$$

where:

A_x = assumption X (1: unit size (RT), 3: Unit gas usage (Btu/RT), 8: Demand diversity)

D_c = the cooling season days.

There remain three size categories of utility-class engine-driven chillers (i.e., > 5 tons), but it is recommended that the size boundaries be modified. The existing boundaries are 5, 50, and 100 tons. The 50 ton boundary should be reduced to 25 tons. Because of the recommended change in boundary Assumption 9 (% chillers between 5 and 100 tons) needs to reflect the new boundary.

The number of chillers replaced is calculated by dividing the installations' total cooling capacity in the respective range by and assumed chiller size. Electrical savings and the gas cost increase are then determined based on the assumptions above. Economic benefit with respect to CFC replacement has not been calculated. However the number of pounds displaced is included in the results. The more likely reference in these calculations is to HCFC since these would be commonly used in electric chillers. The chillers in the size range 100 to 200 RT are assumed to be air-cooled.

Discount quantity value is negotiable. Currently, no discounts were practiced since no larger numbers are being sold to a single customer. Economic life given is meant as time to major engine overhaul. The rest of the system has much longer economic life.

Sources. Direct Contact With Manufacturers; Natural Gas Cooling Equipment Guide, 4th ed., April 1996.

U16. High-Efficiency Gas Boiler (<100 hp)

Background. Buildings isolated from an installation's central heating network use about half of the Army's heating energy. Replacing the older boilers in these buildings with new high efficiency, low NOx boilers could reduce fuel usage and costs significantly. Buildings best suited to conversion are those that have gas-fired boilers in the size range of 1.0 to 3.0 million Btu/hr of output.

This ultra low NOx and high efficiency combustion technology is suitable for all firetube boiler applications and is designed for both OEM and retrofit applications. It combines high efficiency with NOx emission levels less than 20 ppm fired with natural gas at 3 percent oxygen (less than 40 ppm if fired with oil). Its advanced cyclonic combustion technology adds a significant convective component to the radiant heat transfer. Better heat transfer per square foot, and hence higher boiler efficiency results. The combination of high intensity cyclonic combustion and the convective effect of cyclonic flow can almost double the boiler's steam capacity of a conventional boiler. Firing natural gas, this boiler's turndown capability of 10:1 exceeds industry norms of 3 or 4:1.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the Notation Conventions section above for further explanation of numbers in italics, boldface, and/or underlined.)

Efficiency of new boilers	**80-85%**
Approximate boiler horsepower	**60 hp**
Typical Replacement Boiler Size	**2.5 MBtu/hr**
Installed cost	**$21,000-$27,000 ($350-450/hp)**
Recurring cost differential (% of capital)	None
Economic Life	**20 Years**
NOx emission level for new boilers	**20-25 ppm (0.025-0.031 lb/MBtu)**
Discount quantity	10 Units

Facility Assumptions. This ECO applies to all buildings except family housing. The larger boilers are replaced by two high-efficiency boilers with a rating of 40 percent of the original capacity.

Efficiency of conventional boilers	65%
NOx emission level for conventional boilers	112 ppm (0.137 Lb/MBtu)
Typical Boiler Plant Size	**12.9 MBtu/hr**
% Gas boilers <0.75 MBtu/hr	30%
% Gas Boilers 0.75 to 3.5 MBtu/hr	24%

Algorithm Modifications. The units calculation for this ECO is based on a combination of gas heating plant consumption and capacity as well as assumptions 1 and 2 (typical boiler plant size and typical replacement boiler size, respectively). If assumption 2 (replacement size) is changed independently of assumption 1, the total installed capacity for a particular installation can change. Lacking further information concerning the intention of the units calculation, assumptions 1 and 2 have been tied together to yield a consistent total installed capacity when changes in replacement boiler size occur.

The current ECO algorithm does not take into account any additional NOx reduction that advanced technology units may achieve. Although societal costs are not included in the financial evaluation of ECOs, these benefits should be accounted for accurately. In Section 3 of the ECO algorithm, the following relationships should be added:

$$\text{noxaba} = (\text{gasenesav} * \text{xgasnoxemm} + \text{numecouni} * \text{xassum02v} * \text{xfulloahea} \\ * 100/\text{xassum05v} * (\text{xgasnoxemm} - \text{xassum07v}))/2000$$

$$\text{soctotcos} = \text{noxaba} * \text{xsocnoxrat} * 2000$$

U17. High-Efficiency Gas Boiler (100 to 250 hp)

Background. Buildings isolated from an installation's central heating network use about half of the Army's heating energy. Replacing the older boilers in these buildings with new high efficiency, low NOx boilers could reduce fuel usage and costs significantly. Buildings best suited to conversion are those that have gas-fired boilers in the size range of 3.0 to 8.0 million Btu/hr of output.

This ultra low NOx and high efficiency combustion technology is suitable for all firetube boiler applications and is designed for both OEM and retrofit applications. It combines high efficiency with NOx emission levels less than 20 ppm fired with natural gas at 3 percent oxygen (less than 40 ppm if fired with oil). Its advanced cyclonic combustion technology adds a significant convective component to the radiant heat transfer. Better heat transfer per square foot, and hence higher boiler efficiency results. The combination of high intensity cyclonic combustion and the convective effect of cyclonic flow can almost double the boiler's steam capacity of a conventional boiler. Firing natural gas, this boiler's turndown capability of 10:1 exceeds industry norms of 3 or 4:1.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to

Notation Conventions section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Efficiency of new boilers	**80-85%**
Approximate boiler horsepower	**175 hp**
Typical Replacement Boiler Size	**7.25 MBtu/hr**
Installed cost	**$43,750-$61,250 ($250-350/hp)**
Recurring cost differential (% of capital)	None
Economic Life	**20 Years**
NOx emission level for new boilers	**20-25 ppm (0.025-0.031 Lb/MBtu)**
Discount quantity	10 Units

Facility Assumptions. This ECO applies to all buildings except family housing. The larger boilers are replaced by two high-efficiency boilers with a rating of 40 percent of the original capacity.

Efficiency of conventional boilers	65%
NOx emission level for conventional boilers	112 ppm (0.137 Lb/MBtu)
Typical Boiler Plant Size	**37.6 MBtu/hr**
% Gas boilers <0.75 MBtu/hr	30%
% Gas Boilers 0.75 to 3.5 MBtu/hr	24%

Algorithm Modifications. The units calculation for this ECO is based on a combination of gas heating plant consumption and capacity as well as assumptions 1 and 2 (typical boiler plant size and typical replacement boiler size, respectively). If assumption 2 (replacement size) is changed independently of assumption 1, the total installed capacity for a particular installation can change. Lacking further information concerning the intention of the units calculation, assumptions 1 and 2 have been tied together to yield a consistent total installed capacity when changes in replacement boiler size occur.

The current ECO algorithm does not take into account any additional NOx reduction that advanced technology units may achieve. Although societal costs are not included in the financial evaluation of ECOs, these benefits should be accounted for accurately. In Section 3 of the ECO algorithm, the following relationships should be added:

$$\text{noxaba} = (\text{gasenesav} * \text{xgasnoxemm} + \text{numecouni} * \text{xassum02v} * \text{xfulloahea} * 100/\text{xassum05v} * (\text{xgasnoxemm} - \text{xassum07v}))/2000$$

$$\text{soctot cos} = \text{noxaba} * \text{xsocnoxrat} * 2000$$

U18. High-Efficiency Gas Boiler (> 250 hp)

Background. Buildings isolated from an installation's central heating network use about half of the Army's heating energy. Replacing the older boilers in these buildings with new high efficiency, low NOx boilers could reduce fuel usage and costs significantly. Buildings best suited to conversion are those that have gas-fired boilers with an output rate greater than 8.0 million Btu/hr.

This ultra low NOx and high efficiency combustion technology is suitable for all firetube boiler applications and is designed for both OEM and retrofit applications. It combines high efficiency with NOx emission levels less than 20 ppm fired with natural gas at 3 percent oxygen (less than 40 ppm if fired with oil). Its advanced cyclonic combustion technology adds a significant convective component to the radiant heat transfer. Better heat transfer per square foot, and hence higher boiler efficiency results. The combination of high intensity cyclonic combustion and the convective effect of cyclonic flow can almost double the boiler's steam capacity of a conventional boiler. Firing natural gas, this boiler's turndown capability of 10:1 exceeds industry norms of 3 or 4:1.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Efficiency of new boilers	**80-85%**
Approximate boiler horsepower	**400 hp**
Typical Replacement Boiler Size	**16.6 MBtu/hr**
Installed cost	**$80,000-$100,000 ($200-250/hp)**
Recurring cost differential (% of capital)	None
Economic Life	**20 Years**
NOx emission level for new boilers	**20-25 ppm (0.025-0.031 Lb/MBtu)**
Discount quantity	10 Units

Facility Assumptions. This ECO applies to all buildings except family housing. The larger boilers are replaced by two high-efficiency boilers with a rating of 40 percent of the original capacity.

Efficiency of conventional boilers	65%
NOx emission level for conventional boilers	112 ppm (0.137 Lb/MBtu)
Typical Boiler Plant Size	**85.8 MBtu/hr**
% Gas boilers <0.75 MBtu/hr	30%
% Gas Boilers 0.75 to 3.5 MBtu/hr	24%

Algorithm Modifications. The units calculation for this ECO is based on a combination of gas heating plant consumption and capacity as well as assumptions 1 and 2 (typical boiler plant size and typical replacement boiler size, respectively). If assumption 2 (replacement size) is changed independently of assumption 1, the total installed capacity for a particular installation can change. Lacking further information concerning the intention of the units calculation, assumptions 1 and 2 have been tied together to yield a consistent total installed capacity when changes in replacement boiler size occur.

The current ECO algorithm does not take into account any additional NOx reduction that advanced technology units may achieve. Although societal costs are not included in the financial evaluation of ECOs, these benefits should be accounted for accurately. In Section 3 of the ECO algorithm, the following relationships should be added:

$$\text{noxaba} = (\text{gasenesav} * \text{xgasnoxemm} + \text{numecouni} * \text{xassum02v} * \text{xfulloahea} * 100/\text{xassum05v} * (\text{xgasnoxemm} - \text{xassum07v}))/2000$$

$$\text{soctot cos} = \text{noxaba} * \text{xsocnoxrat} * 2000$$

Industrial/Process Applications (ECO Nos. I01 through I07)

The following seven (7) ECOs are covered under this category:

I01. Composite Radiant Tube

I02. Fuel Based Nitrogen Generator

I03. Low-Inertia Heat-Treating Furnace (Flat Plate Heater)

I04. Medical Waste Treatment System

I05. Mineral Wool Melter

I06. Oscillating Combustion Technology

I07. Oxygen-Enriched Air Staging System for Regenerative Glass Furnaces.

These ECOs are described on the following pages of this report as a preliminary reference. These ECOs will need further research and development in future projects to be included in the next version of the REEP program.

I01. Composite Radiant Tube

Background. Single-pass composite radiant tubes (CRTs) are based on silicon and silicon carbide. This ECO is a commercially proven technology for atmosphere heat treating furnaces, and can be used in place of conventional metal alloy and mullite radiant tubes. Benefits of implementing this ECO at

DOD installations include significant cost savings in heat treating operations, reduced downtime, and increased productivity. Figure 9 shows various CRT configurations. This ECO refers to the straight, single-pass configuration only. Other two configurations have not yet been fully deployed in the marketplace. Since CRTs were first introduced in the market, more than 3,500 straight, single-pass tubes have been installed, many of them in batch integral quench furnaces.

When properly installed, CRT resists failure due to creep, thermal shock, carburization (embrittlement), melt-through, and oxidation. Because of their material content, most CRTs are vulnerable to breakage if dropped or struck by heavy objects. Tube breakage during installation and operation can be avoided through training of shop personnel. CRTs can be used in all types of batch and continuous heat treating furnaces. For U-tube applications, composite elbows are being developed to meet the needs of the significant number of heat treating furnace with such configuration.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Conventional	CRT	
Total number of tubes in furnace	20	20
Installed unit cost (material + labor - salvage value) ($/tube)	375	445
Installed unit cost of conversion hardware (one-time only) ($/tube)	N/A	250
Estimated economic life of tube (years)	1.75	3.50
Unit furnace downtime (hours/tube)	2.00	0.40
Value of furnace downtime ($/hour)	150	150

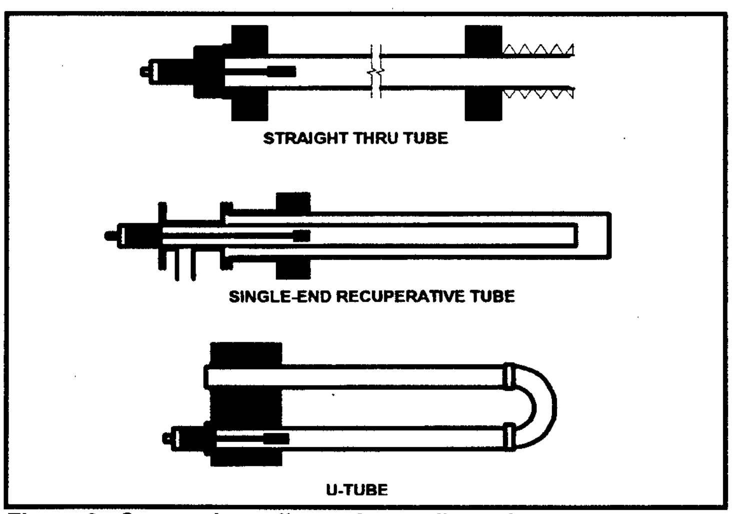

Figure 9. Composite radiant tube configurations.

Algorithm Suggestions. Since this is a new ECO, no appropriate evaluation algorithm is available in the current version of the REEP program. It is suggested that the following relationships be used in calculating simple payback for this ECO:

Incremental First Cost	=	No. tubes in furnace x [{(Installed unit cost for CRT + Installed unit cost of conversion hardware - Installed unit cost for conventional tubes)} - {Value of furnace downtime x (Unit furnace downtime for conventional tubes - Unit furnace downtime for CRT)}]
No. of conventional tubes replaced per year	=	Total no. of tubes in furnace/Economic life of conventional tube
No. of CRTs replaced per year	=	Total no. of tubes in furnace/Economic life of CRT
Annual downtime cost for conventional tubes	=	Value of furnace downtime x No. of conventional tubes replaced per year x Unit furnace downtime for conventional tubes
Annual furnace downtime cost for CRT	=	Value of furnace downtime x No. of CRTs replaced per year x Unit furnace downtime for CRT
Annual savings in furnace downtime cost	=	Annual furnace downtime cost for conventional tubes - Annual furnace downtime cost for CRT
Annual recurring cost for conventional tubes	=	No. of conventional tubes replaced per year x Unit cost for conventional tube
Annual recurring cost for CRT	=	No. of CRTs replaced per year x Unit cost of CRT
Incremental recurring costs	=	Annual recurring cost for CRT - Annual recurring cost for conventional tubes
Net annual savings	=	Annual savings in furnace downtime cost - Incremental annual recurring costs
Simple payback period	=	Incremental first cost/Net annual savings

Sources. Communications with manufacturers. *Composite Radiant Tubes – Benefits, Applications, and Information Resources*, Gas Research Institute, September 1996

102. Fuel Based Nitrogen Generator

Background. Fuel-based nitrogen (FBN) generators are an on-site option for generating nitrogen or nitrogen with controlled percentages of hydrogen (0 to 15 percent) protective atmospheres at low cost. This ECO offers substantial savings compared to competing methods such as fractional distillation, pressure swing adsorption, membrane separation, or liquid nitrogen because it combusts economical natural gas and then purifies the combustion gases. FBN systems feature advanced controls to precisely and reliably monitor the gas chemistry of the output atmosphere, and will produce atmosphere with a dew point below -65 °F while significantly reducing NOx and carbon monoxide emissions. Its engineering and construction are also designed for low maintenance.

Although early applications of this ECO have been in metal processing, it also has a wide range of potential applications in food preservation, pulp and paper production, glass manufacturing, chemicals, and petroleum refining. Nitrogen blanketing creates oxygen-free environments which prevent fires and explosions, and increases long-term storage time for perishable products (American Gas Association 1995). An FBN system can also produce steam for plant use, along with the protective atmosphere, by replacing the firing chamber of the generator with a modified firetube boiler.

Key features of this ECO include low initial and operating costs, production of high purity atmospheres, capability to adjust hydrogen levels, high degree of flexibility in operations, lower NOx and CO emissions, and increased efficiency through heat recovery.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.) It is assumed that the atmosphere output requirement is for a 10,000 cu ft output with 7 percent hydrogen. The following parameters are given on a per 1,000 cu ft of production requirement.

Atmosphere output	10,000 cu ft (with 7 percent hydrogen)
Power consumption	6.1 kW
Water usage	60 Gallons
Natural gas usage	225 Cu ft (with no steam production)
Electricity cost	$0.07/kWh
Water cost	$0.50/1000 gallons
Natural gas cost	$3.85/MBtu
Capital recovery cost	$0.63/1000 cu ft
Total cost of alternative	$2.22/1000 cu ft

Algorithm Suggestions. Simple economic benefit calculations can be done as follows:

Total cost of FBN generator system = (Atmosphere output/1000) x {(Electricity cost x Power consumption) + (Water usage x Water cost) + (Natural gas usage x Natural gas cost)} + Capital recovery cost]

Cost savings = Total cost of alternative - Total cost of FBN generator system

Note that the exact amount of savings would be very site-specific, and will depend on the actual production requirement. Also, the credit for emission reductions should be added to the above benefits.

I03. Low-Inertia Heat-Treating Furnace (Flat Plate Heater)

Background. In many metallurgical processes, such as heat-treating of steel, the product must be heated in a protective atmosphere containing H_2, N_2, and CO with negligible amounts of O_2 and H_2O. The most common approach currently used for indirect-heating applications is a radiant tube combustion system. Radiant tubes can operate at temperatures up to 2000 °F, and the process temperature is usually limited to 1800 °F. Furthermore, the required spacing of tubes and space geometry constraints generally produce nonuniform temperature profiles on the workload resulting in a poor quality of items being produced. Current military specifications require a uniformity of + 25 °F as measured by nine points – corners and center – of a rectangular load.

This ECO, which is currently being field tested by the Institute of Gas Technology and will soon be commercially available in the U.S. market, overcomes the limitations of conventional metallic radiant tube systems by employing self-recuperated gas-fired flat metallic indirect-radiant heaters. These heaters replace the furnace refractory lining and isolate the combustion products from the protective gas atmosphere while providing an increased radiating surface area. Key features of this technology include lower operating temperature (and, therefore, lower NOx emissions), prolonged life at a given production rate, improved product quality, self-recuperation (use of combustion air to cool the burner's outer surface), and higher thermal efficiency (>70 percent).

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Model number	FRH-50
Nominal power	50 kW (170 KBtu/hr)
Length of sides	30 inches
Depth	12 inches
Weight	265 lb
Gas input rate	212 scfh
Nominal gas pressure	0.40 psia
Nominal air pressure	0.25 psia
Turndown ratio	1:3
Noise level	80 dBA
Economic life	5 years
Thermal efficiency	75%
Thermal efficiency of old unit	65%
Reduction in NOx emissions	220 ppm (from 300 ppm to 80 ppm)

Since this ECO is still under development, no cost data is available at this time. It is, however, estimated that the installed cost of this ECO will be on par with that for the conventional alternatives described earlier.

Algorithm Suggestions. The evaluation algorithm for this ECO should highlight reduced gas cost due to higher thermal efficiency, take credit for reduction in NOx emissions using the algorithms already developed in the current version of the REEP program, and account for intangible benefits such as uniformity of combustion and improved product quality.

Source. Communications with the developers at Institute of Gas Technology.

I04. Medical Waste Treatment System

Background. The growing problem of disposing of Regulated Medical Waste (RMW) has prompted many responses, each with its own particular set of constraints. This ECO – a fully automated disposal system that sterilizes all medical waste without the use of combustion, chemicals, microwaves, or other type of radiation – provides a permanent and cost-effective solution that protects the public, hospital personnel, and the environment.

This technology treats medical wastes by steam sterilization, also referred to as "autoclaving." It consists of a treatment vessel and dual-stage shredders with auxiliary equipment that includes control panel, hoppers, and conveyer belts. The required utilities are steam, electricity, air pressure, condenser, and vacuum. Natural gas consumption is about one million Btu per cycle (equivalent to 750 pounds of waste). Key features of this technology include guaranteed sterilization (and not just decontamination and/or disinfection), low operating cost, long service life, no emissions, a large volume reduction, easily expandable, simple to operate, and harmless end-products that can be disposed of as ordinary waste.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Manufacturer's Name	TEMPICO; Madisonville, LA
Model Name and Number	Remedy-One Rotoclave 1500-D2
System Price	$545,000
Installed Cost	$655,000
System Capacity	500 lb/cycle
No. of Cycles/Day	16

Operating Time	345 days/year
Steam Usage	350 lb/cycle
Natural Gas Usage	0.67 MBtu/cycle
Water Makeup	45 gallons/cycle
Economic Life	20 years
Labor and Maintenance Cost	$18.00/cycle
Cost of Conventional Treatment	$250 to $400 per ton

Algorithm Suggestions. The evaluation algorithm for this ECO should calculate the cost of treatment on a per ton basis by multiplying the total cost number by a factor of 2.00 (i.e., 1000/500). This number should then be compared to the cost of the conventional treatment (incineration, stationary autoclave, shredding, dry heat sterilization, dry heat disinfection, electrochemical deactivation, chemical disinfection, microwave disinfection, etc.), which is normally quoted in terms of $/ton of waste. When compared to conventional technologies such as incineration, additional credits for emission reductions should also be taken into consideration.

Sources. Direct communications with the manufacturer, Industrial Gas Technology Commercialization Center, Arlington, VA, October 1994.

I05. Mineral Wool Melter

Background. Mineral wool is produced by melting basalt and blast furnace slag in coke-fired cupolas. Environmental concerns over high-temperature furnaces, especially coke-fired units, are leading to the development and increased market penetration of electric melters. This emerging novel technology uses a submerged combustion melting process where natural gas and oxidant (preheated air, enriched air, or oxygen) are fired directly into and under the surface of the bath of the material being melted. Combustion products bubbling through the bath provide very effective heat transfer, reduce the overall temperature of the gases and, thereby, reduce NOx emissions. The bubble increases bath turbulence, promoting melt composition homogeneity. Also, any carbon or organic material in the feed is used, enhancing thermal efficiency. Figure 10 below depicts a cut-away drawing of a submerged combustion melter (Gordon 1994). This ECO produces negligible amounts of NOx, CO, and H_2S emissions. In summary, it offers clear economic, productivity, and environmental advantages in making mineral wool and other products such as cement, sodium silicate, etc., which are formed by high-temperature melting processes.

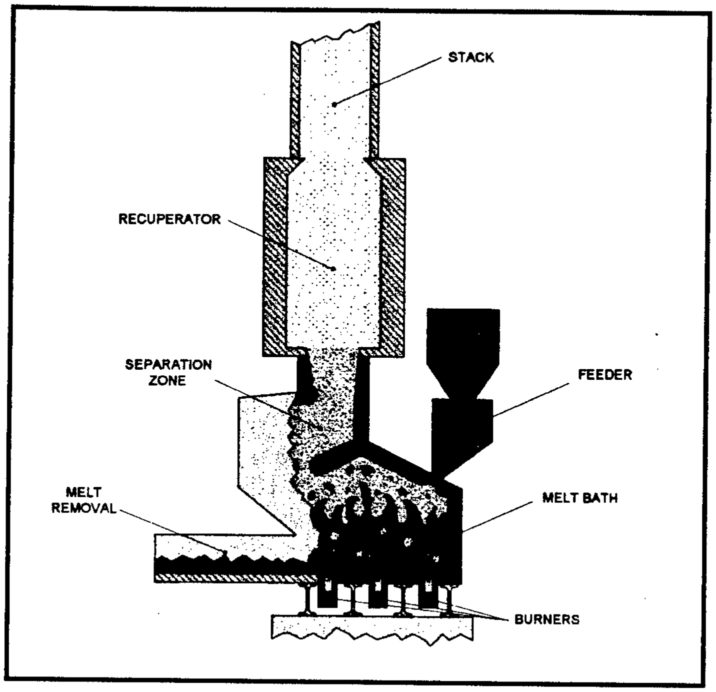

Figure 10. Submerged combustion melter.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Unit Capacity	3.0 ton/hour (75 ton/day)
Installed Cost	75 to 80% of installed cost for conventional melter
Reduction in NOx Emissions	900 ppm (from 1000 ppm to 100 ppm)
Reduction in CO2 Emissions	30 lb/ton (from 128 lb/ton to 98 lb/ton)
Thermal Efficiency	60 to 65%
Thermal Efficiency of Old Unit	30 to 35%

Algorithm Suggestions. Since this ECO is not yet commercially available, no data on costs and economic life exist at this time. It is suggested that the evaluation algorithm in the revised version of the REEP program take into account the benefits of compact size, lower first cost, higher efficiency, and increased production rate. The algorithms in the current version of the REEP program can be implemented here as far as calculations of benefits related to emission reductions are concerned.

I06. Oscillating Combustion Technology

Background. Oscillating combustion involves the creation of successive, NOx formation retarding, fuel-rich and fuel-lean zones within the furnace (See

Figure 11 below). The net effect of this process is to lower the peak flame temperature, increase the formation and total oxidation of soot for radiative cooling and enhanced flame radiative heat transfer. It should be noted that the oscillating combustion does not change the overall stoichiometry.

An economic benefit of this emerging technology is that in principle it does not require new special burner designs or cumbersome modifications to accommodate the oscillations. This ECO can easily be implemented into existing oxy-gas or air-gas combustion systems by installing solenoid, rotary, or solid-state oscillating valve(s) into the gas and/or oxidant supply line(s). A concept valve manufactured by Ceramphysics, Inc., of Westerville, OH, has shown significant promise for this application. In laboratory tests, this valve has operated for over 110 million cycles without any retardation in performance.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.)

Burner Capacity	250,000 Btu/hour
NOx Reduction with this ECO	65% (when firing with ambient air)
75% (when fired with preheated air)	
Increase in Heat Transfer to Load	10%

Since this technology is still under development, data on costs and economic life are not yet available.

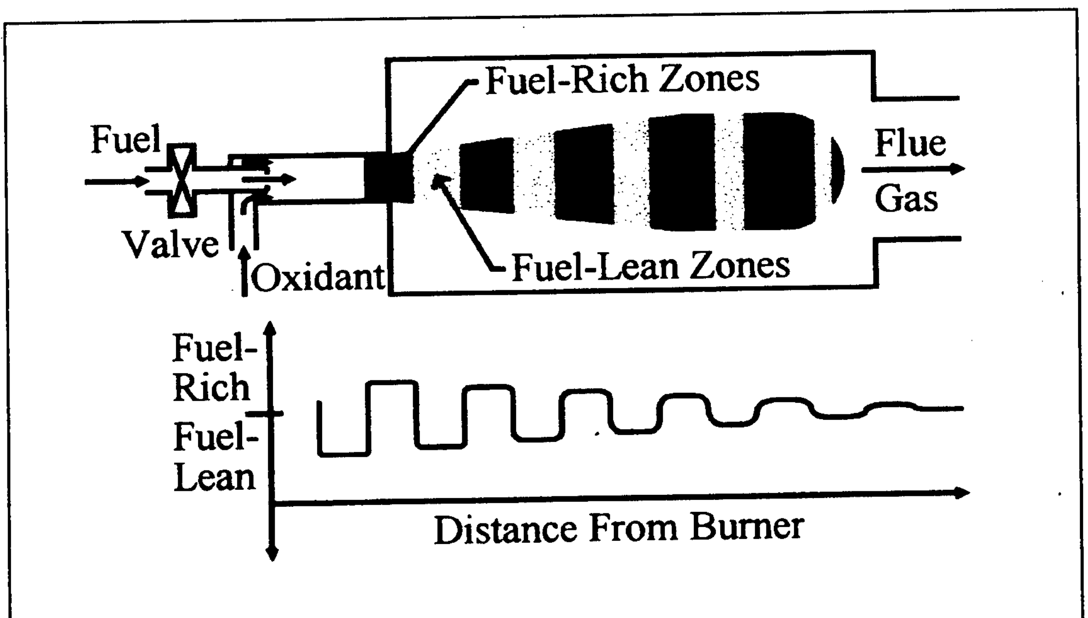

Figure 11. Oscillating combustion process.

Algorithm Suggestions. The evaluation algorithm for this ECO should account for the following benefits: reduced NOx emissions, lower cost of NOx reduction, increased productivity, and negligible first cost.

107. Oxygen-Enriched Air Staging (OEAS) System for Regenerative Glass Furnaces

Background. OEAS is the most advanced retrofit NOx control process of its kind for regenerative glass furnaces. Oxygen-driven ejectors installed at strategic locations on the furnace and the patented overall combustion process produce extraordinary low NOx emissions. Implementation of this ECO at DOD facilities will result in enhanced emission performance, better glass quality, and a furnace operation that is transparent to the process. Regenerative glass melting furnaces are high-temperature furnaces, typically operating at melting temperatures of 1800 to 2800 °F, resulting in NOx emission levels as high as 10 lb per ton of glass produced. The container glass industry accounts for nearly 3 out of every 4 regenerative glass furnaces operating in the United States. Figure 12 below depicts a schematic diagram for OEAS as applied to an endport glass melting furnace.

ECO Assumptions. Technical and economic performance parameters and other relevant details pertaining to this ECO are given below. (Please refer to the ***Notation Conventions*** section above (p 42) for further explanation of numbers which are shown in *italics*, **boldface**, and/or underlined.) Since this ECO is a retrofit technology, the installed cost for it would be very site-specific.

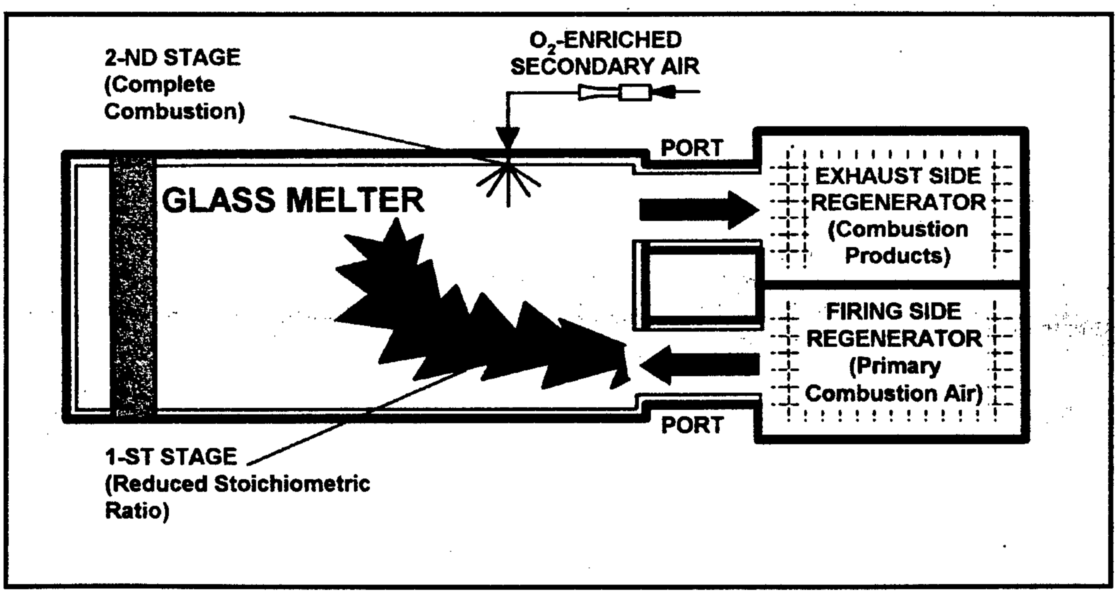

Figure 12. OEAS for an Endport Glass Melting Furnace.

Therefore, no typical cost figures can be provided. However, as a rule of thumb, it is assumed that the incremental cost of OEAS will be approximately $1.00 per ton of glass produced. Alternative NOx reduction techniques include cullet preheating, electric boosting, selective non-catalytic reduction, selective catalytic reduction, and oxy-fuel firing.

The implementation cost for these techniques range from $3000 to $7000 per ton of NOx removed. In comparison, the OEAS costs no more than $400 per ton of NOx removed. Based on a number of field tests conducted on endport furnaces, it has been demonstrated that OEAS reduces 44 to 73 percent of NOx emissions (from a baseline of 4.5 to 7.8 lb/ton of glass produced to 1.8 to 3.3 lb/ton of glass produced).

Algorithm Suggestions. Because of its site-specific nature, this ECO should not be evaluated on a national or regional level with a single set of technical and economic assumptions. It is suggested that the current REEP algorithms designed to calculate the benefits of NOx reductions be employed for each retrofit site evaluation.

Standard REEP Output for Natural Gas Technologies

Methodology

One method for evaluating the potential impact of various natural gas technologies is to use the Renewables and Energy Efficiency Planning (REEP) software developed at USACERL. The REEP software performs a generalized energy/financial/pollution analysis for energy saving technologies at DOD installations in the continental United States. Facility data, weather data, utility rates, and electrical generation mix are contained in installation database files. An initial analysis applies algorithms for each technology to the various data to produce energy savings estimates. These estimates are then used in an economic analysis that considers regional pricing and life-cycle factors. The economic analysis is based on the DOD's Energy Conservation Investment Program (ECIP) standards. The economic results are then filtered through user-set minimum requirements. To address the possibility of competing technologies, the analyst can select competition criteria (like simple payback) and run a separate analysis to exclude competing technologies that are less attractive. Pollution abatement estimates are then calculated based on the energy savings and regional electrical generation mix. Finally, all of the results are totaled across the selected installations.

For this analysis, a technology was considered economically viable if it had a simple payback of ten years or less, and a savings to investment ratio 1.25 or greater. REEP offers a wide variety of energy conservation technologies. For this analysis, only the natural gas technologies were selected. The natural gas technologies currently found in REEP (including those gas technologies added or revised as part of this project) are:

Building HVAC Systems

- Desicnt Clg - Latent 25-100 tons
- Desicnt Clg - Latent 5-25 tons
- Desicnt Clg - Latent > 100 tons
- Desicnt Clg -LatSens 25-100 tons
- Desicnt Clg -LatSens 5-25 tons
- Enthalpy Recvry Desscnt Wheel

Family Housing HVAC Systems

- FH Desicnt Clg - LatSens
- FH Desic. Clg - Latent Only
- FH Flame Ret. Burners
- FH Gas Engine Drvn HP
- FH HiEf Gas Furn: Condensing
- FH HiEf Gas Furn: Pulse Combst
- FH HiEf Gas Furn: Recuperative
- FH Nom Eff Gas Furn

Utilities & Heating/Cooling Plants

- Cogen - Fuel Cell
- Cogen - Gas Turbine 5-20 MW
- Cogen - Gas Turbine < 5 MW
- Cogen - Recp. Engine .5-2 MW
- Cogen - Recp. Engine 100-500 kW
- Cogen - Recp. Engine < 100 kW
- Cogen - Recp. Engine > 2MW
- DF Gas Chillers 25-100 tons

- DF Gas Chillers 5-25 tons
- DF Gas Chillers <5 tons
- DF Gas Chillers >100 tons
- Flame Retention Burners
- Gas Engine Air Compressors
- Gas Engine Water Pump
- GasEng Chillers 25-100 tons
- GasEng Chllrs 5-25 tons
- GasEng Chllrs >100 tons
- High Eff. Gas Boiler 100-250 hp
- High Eff. Gas Boiler < 100 hp
- High Eff. Gas Boiler > 250 hp
- Oil Nomeff Boiler

Note that some of these technologies compete. Each "Cogen" technology is a competing technology for the other cogen technologies. Likewise, direct-fired chillers are competing with gas engine chillers.

REEP Analysis Results

As required by REEP, initially a Simple Analysis (no screening or eliminating competing technologies) was performed. All DOD installations were included. Only the gas related ECOs (as listed above) were selected. Following the Simple Analysis, the Financial, Resource, and Pollution analysis were run and results are shown in Tables 9, 10, and 11, respectively. In the tables, the Cogen technologies are broken out with a separate subtotal. The Cogen technologies are capable of greatly increasing the totals to levels which may not be realistic; given the real world practical limits imposed by the need to reduce physical plant ownership (privatization) and associated maintenance despite the potential savings, or other policy and financial limitations. The Cogen subtotals in tables X-1, X-2, and X-3 are "competed" results; only the most economical choice is listed as an opportunity for sites where more than one type of Cogen was applicable. To provide an indication of the total (non-competed) potential application for each of the cogen technologies, Table 12 shows the total number of opportunities listed in the REEP Simple Analysis (with less than a 10 year simple payback and an SIR greater than 1.25).

The subtotal for gas technologies (without Cogen) indicates more than 60,000 ECO opportunities with yearly savings of $101M for the investment of $465M; approximately a 4.6 year payback. Of the 61,000 opportunities, about 41 percent are family housing furnaces and heat pumps. The other ECO with a large numbers of opportunities DF Gas Chiller <5 tons (18977 opportunities). The Flame Retention Burners and Gas Engine Air Compressors achieved the lowest simple paybacks among the non-Cogen ECOs with paybacks less than 2.5 years.

Cogen - Recip. Engines 100-500kW exhibited the lowest payback (1.49 years) of all ECOs. This ECO, with only 1211 opportunities, adds significantly to the savings and initial cost totals at the bottom of the table. In this competitive analysis (screening based on economics with no credit for pollution abatement), fuel cells were not selected for any sites. (See Table 12 for fuel cell opportunities.)

For the non-Cogen ECOs, annual energy savings was negative 4.5 million MBTUs/yr. Total energy consumption increased (even though energy costs were reduced as shown in the previous table). This is to be expected since many of the gas technologies produce cost savings by replacing expensive electrical consumption with cheaper gas energy consumption. Implementation of the non-Cogen ECOs is estimated to increase annual gas consumption by 12 million MBTUs/year while reducing electrical consumption 5 million MBTUs/year. Adding in the Cogen ECOs once again significantly changes the totals. The Cogen annual dollar savings is larger than the total dollar savings for all other ECOs combined.

This table provides estimates of abated pollution. Pollution values (for an assumed mix of electrical generation types for the region of the United States where the military installation is located) is used along with the REEP estimate of energy savings for each ECO to calculate abated pollution. Abated pollution from each site is summed to arrive at the abated pollution show in the table for each ECO.

This table shows a (non-competitive) financial summary for each of the three Cogen technologies; Fuel Cells, Gas Turbines, and Recip. Engines. Only opportunities with less than a 10-year payback and greater than a 1.25 SIR were included. The ECO Recip. Engine 100-500kW had the greatest number of opportunities (1211) and the lowest simple payback (1.5 years). Fuel cell opportunities which were screened out by Recip. Engines during the previous (competitive) analysis is estimated at 430 opportunities, $167 million initial cost, and $23 million per year savings with a 7.3 year payback.

Table 9. Financial summary.

		Number of Installations	Number of Opportunities		Initial Cost ($	Total Dollar Savings/Year ($/Yr)	Simple Payback Years	SIR Ratio
	Building HVAC							
1	Enthalpy Recvry Desscnt Wheel	197	3226	Wheels	39,006,930	12,919,303	3.02	5.57
	Family Housing HVAC							
2	FH Flame Ret. Burners	19	4052	Burners	2,031,844	817,278	2.49	5.43
3	FH Gas Engine Drvn HP	1	840	Heat Pumps	5,283,532	1,136,950	4.65	1.89
4	FH Nom Eff Gas Furn	39	20011	Furnaces	16,212,783	2,317,459	7	2.77
	Utilities/Heat&Cooling Plants							
5	Flame Retention Burners	126	6536	Burners	5,963,579	3,710,351	1.61	8.41
6	Gas Engine Air Compressors	26	31	Engines	5,362,650	3,319,459	1.62	5.2
7	High Eff. Gas Boiler > 250hp	27	29	Boilers	2,969,568	951,765	3.12	6.3
8	High Eff. Gas Boiler 100-250hp	58	82	Boilers	4,930,992	1,338,553	3.68	5.29
9	DF Gas Chillers >100Tons	39	656	Chillers	117,501,973	27,838,113	4.22	3.59
10	Gas Engine Water Pump	102	725	Engines	59,107,601	13,701,253	4.31	2.76
11	High Eff. Gas Boiler < 100hp	98	247	Boilers	6,835,844	1,564,248	4.37	4.44
12	GasEng Chllrs >100 Tons	2	15	Chillers	3,770,020	758,560	4.97	1.57
13	GasEng Chllrs 25-100 Tons	12	443	Chillers	47,485,577	8,430,298	5.63	1.53
14	GasEng Chllrs 5-25 Tons	1	46	Chillers	1,295,986	219,693	5.9	1.47
15	Oil Nomeff Boiler	100	3721	Boilers	18,739,928	2,853,043	6.57	2.06
16	DF Gas Chillers <5Tons	47	18977	Chillers	105,639,718	16,049,872	6.58	2.49
17	DF Gas Chillers 5-25Tons	11	875	Chillers	23,339,668	3,458,425	6.75	2.25
	Subtotal (1 thru 17)	905	60512		465,478,193	101,384,623	4.59	3.13
18	Cogen - Recp. Engine 100-500Kw	125	1211	Engines	155,612,628	104,302,077	1.49	7.3
					Cost	**Savings**	**Payback**	**SIR**
	Totals				621,090,821	205,686,700	3.02	4.17

Table 10. Energy summary.

		Total Energy Savings MBTU/Yr	Electricity Savings MBTU/Yr	Demand Savings MBTU/Yr	Gas Savings MBTU/Yr	Oil Savings MBTU/Yr	Coal Savings MBTU/Yr
	Building HVAC						
1	Enthalpy Recvry Desscnt Wheel	2,150,105	249,115	59,856	1,182,602	547,705	170,683
	Family Housing HVAC						
2	FH Flame Ret. Burners	157,961				157,961	
3	FH Gas Engine Drvn HP	(42,265)	60,145	2,465	(102,410)		
4	FH Nom Eff Gas Furn	559,296	(16,060)		575,356		
	Utilities/Heat & Cooling Plants						
5	Flame Retention Burners	1,027,341				1,027,341	
6	Gas Engine Air Compressors	(6,727)	238,390	25,699	(245,117)		
7	High Eff. Gas Boiler > 250hp	256,014			256,014		
8	High Eff. Gas Boiler 100-250hp	336,984			336,984		
9	DF Gas Chillers >100Tons	(5,963,531)	2,176,943	124,689	(8,140,474)		
10	Gas Engine Water Pump	(1,894,131)	1,122,594	150,225	(3,016,725)		
11	High Eff. Gas Boiler < 100hp	371,631			371,631		
12	GasEng Chllrs >100 Tons	(107,262)	69,649	2,448	(176,911)		
13	GasEng Chllrs 25-100 Tons	(1,018,564)	594,357	34,022	(1,612,921)		
14	GasEng Chllrs 5-25 Tons	(25,415)	12,754	883	(38,169)		
15	Oil Nomeff Boiler	625,745			-	625,745	
16	DF Gas Chillers <5Tons	(285,684)	580,827	45,541	(866,511)		
17	DF Gas Chillers 5-25Tons	(648,797)	236,836	13,860	(885,633)		
	Subtotal (1 thru 17)	(4,507,299)	5,325,550	459,688	(12,362,284)	2,358,752	170,683
18	Cogen - Recp. Engine 100-500Kw	(10,973,868)	14,666,700	526,785	(25,640,568)		
		Total	**Electricity**	**Demand (kW)**	**Gas**	**Oil**	**Coal**
	Totals	(15,481,167)	19,992,250	986,473	(38,002,852)	2,358,752	170,683

Table 11. Pollution summary.

		SOx Abated Tons	NOx Abated Tons	Particulate Abated Tons	CO Abated Tons	CO2 Abated Tons	Hydrocarbons Abated Tons
	Building HVAC						
1	Enthalpy Recvry Desscnt Wheel	898	360	40	58	189,483	3
	Family Housing HVAC						
2	FH Flame Ret. Burners	54	16	3	3	13,427	0
3	FH Gas Engine Drvn HP	134	37	7	1	9,464	0
4	FH Nom Eff Gas Furn	(30)	29	(1)	9	29,633	0
	Utilities/Heat&Cooling Plants						
5	Flame Retention Burners	352	104	17	18	87,324	1
6	Gas Engine Air Compressors	347	145	21	5	37,639	1
7	High Eff. Gas Boiler > 250hp	-	18	0	4	14,721	-
8	High Eff. Gas Boiler 100-250hp	-	23	1	6	19,377	-
9	DF Gas Chillers >100Tons	3,807	1,137	223	(56)	38,929	10
10	Gas Engine Water Pump	1,794	632	110	(7)	84,308	5
11	High Eff. Gas Boiler < 100hp	0	25	0	6	21,369	0
12	GasEng Chllrs >100 Tons	25	(1)	(0)	(1)	(3,568)	(0)
13	GasEng Chllrs 25-100 Tons	701	309	51	(1)	43,298	2
14	GasEng Chllrs 5-25 Tons	28	8	1	(0)	714	0
15	Oil Nomeff Boiler	215	63	11	11	53,189	1
16	DF Gas Chillers <5Tons	1,003	307	48	5	63,677	2
17	DF Gas Chillers 5-25Tons	288	115	21	(4)	5,542	1
	Subtotal (1 thru 17)	9,616	3,326	555	56	708,525	26
18	Cogen - Recp. Engine 100-500Kw	23,490	8,318	1,349	126	1,720,171	63
		SOx	**NOx**	**Particulate**	**CO**	**CO2**	**Hydrocarbons**
	Totals	33,107	11,644	1,904	181	2,428,696	89

Table 12. Simple analysis - cogen only.

	Number of Opportunities	Number of Installations	Initial Cost $	Total Dollar Savings/Year $/yr	Simple Payback	SIR
Cogen - Fuel Cell	430	29	$167,468,806	$22,881,199	7.3	2.03
Cogen - Gas Turbine < 5MW	64	47	$386,922,145	$98,608,256	3.9	3.60
Cogen - Gas Turbine 5-20MW	27	24	$287,248,842	$85,138,599	3.4	4.20
Cogen - Recp. Engine < 100Kw	667	18	$52,104,041	$10,511,017	5.0	2.56
Cogen - Recp. Engine 100-500Kw	1211	125	$155,612,628	$104,302,077	1.5	7.30
Cogen - Recp. Engine .5-2MW	198	63	$230,921,122	$74,177,111	3.1	3.71
Cogen - Recp. Engine > 2MW	129	71	$234,221,088	$90,197,885	2.6	4.37

6 Conclusions and Recommendations

Conclusions

The results of this research effort will provide DOD facility engineers with a set of performance criteria for selected current and advanced natural gas technologies. These criteria can then be used by the Government to develop technology screening agents for the Renewables and Energy Efficiency Planning (REEP) program. Successful inclusion of these criteria and/or algorithms in the revised version of the REEP program will allow DOD facility planners to take full advantage of the state-of-the-art gas-fired heating, cooling, power generation, and industrial process technologies and, thereby, optimally expand the use of natural gas at most military installations.

The following highlight the key conclusions derived from the results of this research effort:

- A comprehensive state-of-the-art assessment conducted as a part of this research effort clearly revealed a large portfolio of advanced natural gas technologies that are commercially available and can readily be implemented at DOD installations to realize benefits in very short duration.

- The proposed rearrangement and expansion of Energy Conservation Opportunities (ECOs) from two categories (HVAC and Utilities) to four (Family Housing HVAC Systems, Building HVAC Systems, Utilities and Heating/Cooling Plants, and Industrial/Process Applications) will facilitate screening of potential gas-fired ECOs by their market/applications and thereby enable quicker prioritization and optimal allocation of limited resources as far as actual implementation of selected ECOs at DOD installations is concerned.

- A survey of manufacturers and providers of advanced natural gas technologies and related services has revealed that wide ranges of sizes and configurations of a large number of advanced natural gas utilization technologies are commercially available today to precisely match the needs of the end-users.

- A subset of ECOs included in the report is not yet commercially available, but is likely to be deployed in the near future. These emerging technologies represent significant benefits if they were to be implemented at DOD facilities in coming months or years. Their inclusion in the next version of the REEP program will, therefore, help facility planners in making more meaningful and informed decisions as they prepare multi-year strategic plans for their facilities.

- Many manufacturers and LDCs have expressed their interest and willingness in helping the military implement advanced natural gas technologies at DOD installations. Industry organizations have also shown interest in selecting DOD installations as their field sites to demonstrate the technical and economic viability of a number of technologies that are being developed and/or are nearing deployment.

- This research effort has identified a number of installation-related parameters that the facility planner should consider even before he/she can evaluate a specific ECO for his/her facility. These parameters include, but are not necessarily limited to, availability of natural gas, daily and seasonal load profiles, peak-to-base load ratio, piping system layout and configuration, operating pressure range, cost of energy sources, regulatory requirements, compatibility with existing facilities, and social/political considerations.

- An overview of selected ECO evaluation algorithms in the current version of the REEP program has indicated that there exists a need to modify a number of existing assumptions and to create several new ones to properly address data on heating/cooling season days, part-load performance, coincidence of thermal and electric loads, units calculation, etc.

Recommendations

Current Federal energy policies promote increased use of clean-burning natural gas for heating, cooling, power generation, and other industrial/process applications. While the current version of the REEP program is perhaps adequate for screening and planning decisionmaking at a macro level, based on the result of this research effort, the following recommendations are offered to enhance the utility of the next version of the program and to increase the likelihood of implementing advanced natural gas technologies at DOD installations in an efficient, cost-effective, and optimal manner:

- So that the DOD can take full advantage of all synergies involved, all procedures and guidelines for the screening, selection, and implementation of advanced natural gas technologies DOD facilities should be standardized, and uniform selection and resource allocation criteria should be established for most typical of situations.

- DOD facility planners and engineers should be made aware of the revised version of the REEP program and provided with guidelines for collection of relevant installation-specific energy use data.

- DOD facility planners and engineers should be made aware of the availability of advanced natural gas technologies, and regional resource directories be developed to facilitate their continuous interaction with local utilities, equipment manufacturers, and service providers.

- The Defense Energy Information System (DEIS) database should be complemented with the development of information on specific applications and/or uses tied to each energy product. The combined data will then provide a more focused picture as to the identification of specific locations and application areas where the use of natural gas can be optimally expanded.

- Since most DOD facilities do not have meters at individual buildings, the level of detail necessary for the selection and implementation of certain load-sensitive gas-fired ECOs is not available. In lieu of this, it is suggested that a survey be done to update REEP ECO penetration rates. This will enable REEP to better estimate ECOs despite the lack of metering information.

- A special section should be devoted in the next version of the REEP program to address all of the common topics that are discussed in Chapter 5 and Appendix B. These topics range from handling of installation-related data to screening/evaluation of cooling and cogeneration technologies and from units calculation to alternative energy consumption computation techniques.

- The number and categories of ECOs should be reorganized and expanded per Table 8 of the report (p 42) to facilitate more accurate and meaningful screening and evaluation of advanced natural gas technologies.

- Evaluation algorithms and associated assumptions for existing ECOs should be modified per suggestions listed under each ECO description (Chapter 5). Appendix C includes current REEP ECO algorithms for reference.

- A program module should be developed to interface with an existing ECO database so that additional ECOs in a similar application area can be easily added without having to creating separate hard-coded algorithms.

- Since a retrofit ECO's implementation potential is likely to be site-specific, a feature be included in the revised version of the REEP program that ensures that such ECOs are excluded from any analysis/report done at a national/regional level. Otherwise, the implementation potential for retrofit ECO(s) may be overestimated.

- A feedback mechanism be established for REEP users to provide their inputs/reactions to further enhance the utility of the program, send installation-related data/updates to USACERL, and avoid duplication of effort by staying abreast of screening/evaluations of similar ECOs at other DOD installations. An internet-based discussion database or a forum may be an appropriate way to implement this recommendation.

In summary, the technical, economic, social, political, and environmental parameters that DOD facility planners may use in screening/evaluating alternative ECOs for their military installations are already covered in the current version of the REEP program. Its utility can be significantly enhanced by implementing the reorganization/expansion of existing ECOs and incorporating additional ECOs as suggested in this report.

References

Abbasi, H.A. et al., "A Low-NOx Retrofit Technology for Regenerative Glass Melters," *International Gas Research Conference* (Cannes, France, November 1995)

ARI Standard 340/360-93, *Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment*.

ARI Standard 550-92, *Centrifugal and Rotary Screw Water Chilling Packages*.

Composite Radiant Tubes for Atmosphere Heat Treating – Benefits, Applications, and Information Resources (Gas Research Institute, Chicago, IL, September 1996).

Department of the Army (DA), Technical Manual (TM) 5-785, *Engineering Weather Data* (Washington, DC, 1 July 1978).

Defense Energy Information System (DEIS), Office of the Under Secretary of Defense (Production and Logistics) Publication DOD 5126.46-M (February 1990).

Erinov, A.E. et al., "Development of a Gas-Fired, Low-Inertia, High-Efficiency Heat Treating Furnace," *International Gas Research Conference* (Cannes, France, November 1995).

"FBN Generator Meets Tough standards," *Natural Gas Applications in Industry*, published by the American Gas Association as a Gas Technology Supplement to Plant Engineering Magazine, Fall 1995.

Gordon, J., *Evaluation of the Rotoclave Technology for Treatment of Medical Wastes* (Industrial Gas Technology Commercialization Center, Arlington, VA, October 1994).

Natural Gas Cooling Equipment Guide, 4th ed. (The American Gas Cooling Center, Inc., April 1996).

Nemeth, R.J. et al., *Department of Defense (DOD) Renewables and Energy Efficiency Planning (REEP) Program Manual*, Automated Data Processing (ADP) Report 95/20/ADA299345 (U.S. Army Construction Engineering Research Laboratories [USACERL], August 1995).

Ottinger, R.L. et al, *Environmental Costs of Electricity* (Oceana Publications, Inc., 1990).

Petersen, S.R., *Present Worth Factors for Life-Cycle Cost Studies in the Department of Defense (1996)*, NISTIR 4942-3 (National Institute of Standards and Technology, October 1995).

Petersen, Stephen R., *Energy Prices and Discount Factors for Life-Cycle Cost Analyses*, NISTIR 85-3273-8 (U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, published annually).

Ruiz, R. et al., "Oscillating Combustion: An Innovative NOx Emissions Control Approach," *International Gas Research Conference* (Cannes, France, November 1995).

Thomas Register of American Manufacturers, 1996 Edition (Thomas Publishing Company, New York, January 1996).

U.S. Army Engineering and Housing Support Center (USAEHSC, now known as the U.S. Army Center for Public Works, or USACPW), *Facilities Engineering and Housing Annual Summary of Operations, Volume III - Installations Performance, Fiscal year* 1993 (Office of the Assistant Chief of Engineers, USAEHSC, 1993).

U.S. Historical Climatology Network (rev. 3): Monthly Mean Maximum Temperature for June through August, 1996.

Waukesha Cogeneration Handbook, Fourth Edition (Waukesha Engine Division, Dresser Industries, Inc., 1996).

Appendix A: REEP Analysis and Results for Selected Gas Technologies

This section compares the REEP simple analyses for selected advanced natural gas technologies that were examined. Only those ECOs that did not require algorithm changes are examined because algorithm changes will require recoding and recompiling of the REEP program.

Gas Engine-Driven Heat Pump (ECO No. F03)

Figure A1 shows the distribution of REEP simple analysis results using the existing and revised (new) assumption values for gas engine-driven heat pumps. The installation counts are only for those with "passing" payback logic test values, i.e., those DoD installations where the ECO yields a simple payback period of less than 10 years and a savings-to-investment ratio of more than 1.25. Despite higher furnace output and heating and cooling efficiencies, the higher revised capital and maintenance cost resulted in fewer "passed" installations (though the fewer installations do have generally shorter payback times).

Figure A2 shows the breakdown of all installations for the current and revised ECO No. F03, Gas Engine-Driven Heat Pump. *Adopted* are the installations that "passed" the payback logic test. *Not Viable* are the installations with no adopted units (numecouni = 0). *No Savings* are the installations that, although adopted units was greater than zero, no savings accrued (i.e., a simple payback value of zero). The remainder of the installations fall under the *Insufficient Savings* category (i.e., the units adopted generated savings, but the installation could not meet one or both of the payback logic test criteria). In Figure A2, the change in *Adopted* installations is seen again, but the change is relatively small considering the total number of installations.

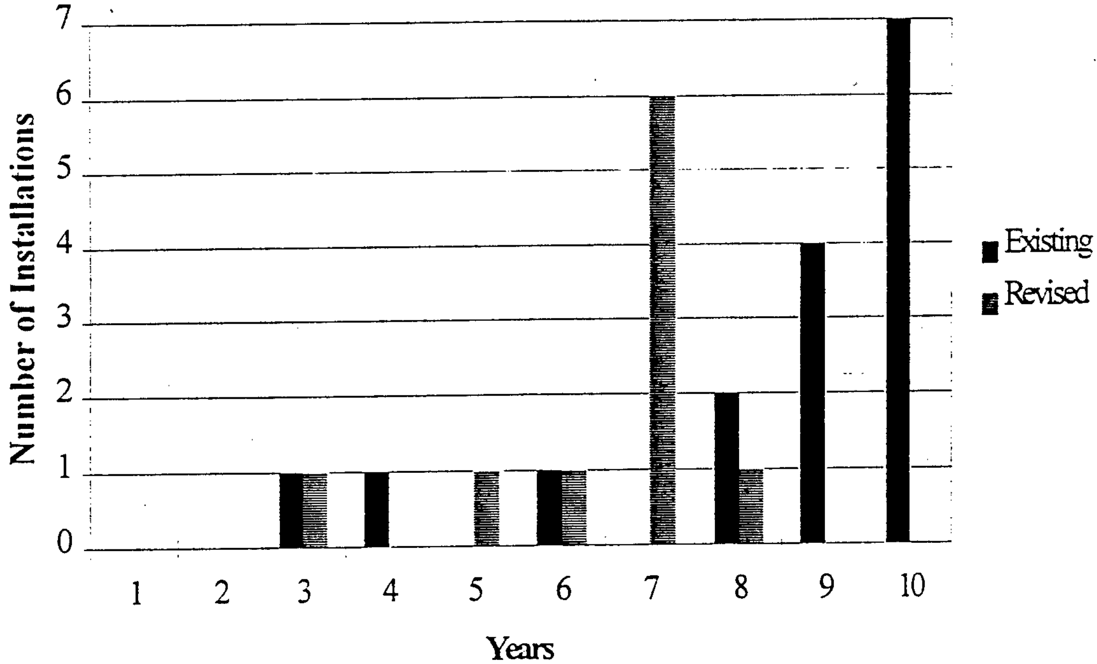

Figure A1. Simple payback distribution: gas engine-driven heat pump (ECO No. F03).

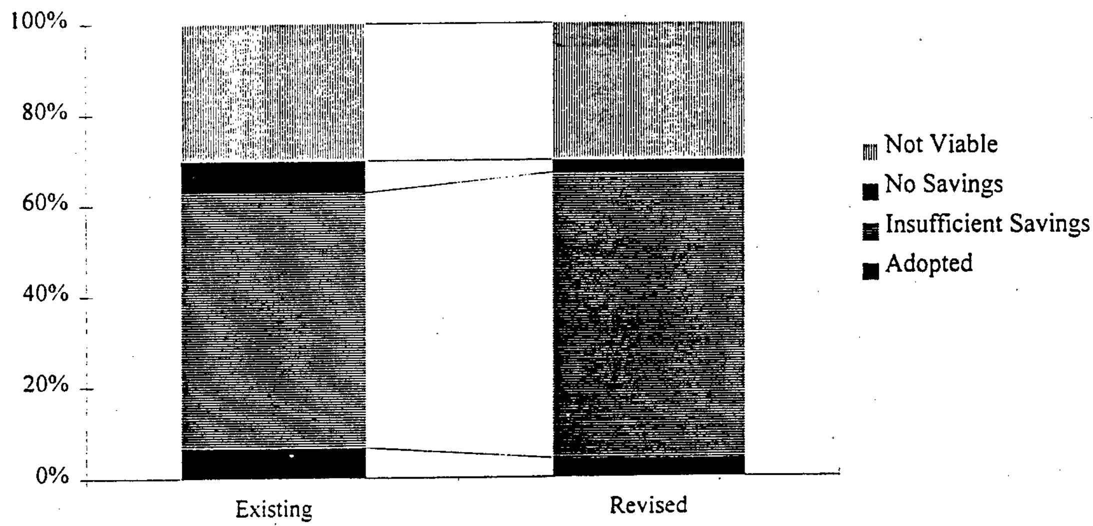

Figure A2. Base installation analysis: gas engine-driven heat pump (ECO No. F03).

Figure A3 shows the average values for all non-zero simple payback results, all "passing" simple payback results, and all "passing" savings-to-investment ratio results. The drop in the three average values in Figure A3 likely results from a combination of a decrease in the number of "passing" installations as well as the increase in heat pump efficiencies.

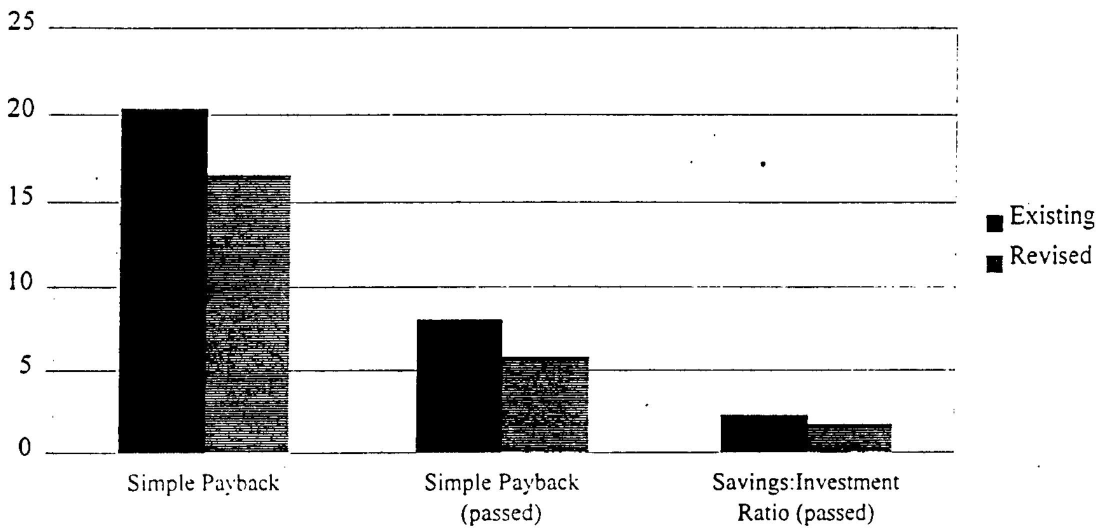

Figure A3. Average investment criteria: gas engine-driven heat pump (ECO No. F03).

High-Efficiency Gas Furnaces (ECO Nos. F04 through F06)

Figures A4 through Figure A6 show a similar set of analysis and results for high-efficiency gas furnaces (ECO Nos. F04 through F06). There are far fewer *Adopted* installations for high-efficiency gas furnaces as the revised data exhibit higher maintenance costs and higher capital costs for all but the recuperative model. The recuperative model also has a lower efficiency value compared to the existing assumptions. These factors lead to the shift in payback distributions seen in Figure A4.

We see the drop in *Adopted* installations again in Figure A5, and the revised assumption values have shifted more installations from *Insufficient Savings* to *No Savings* as well.

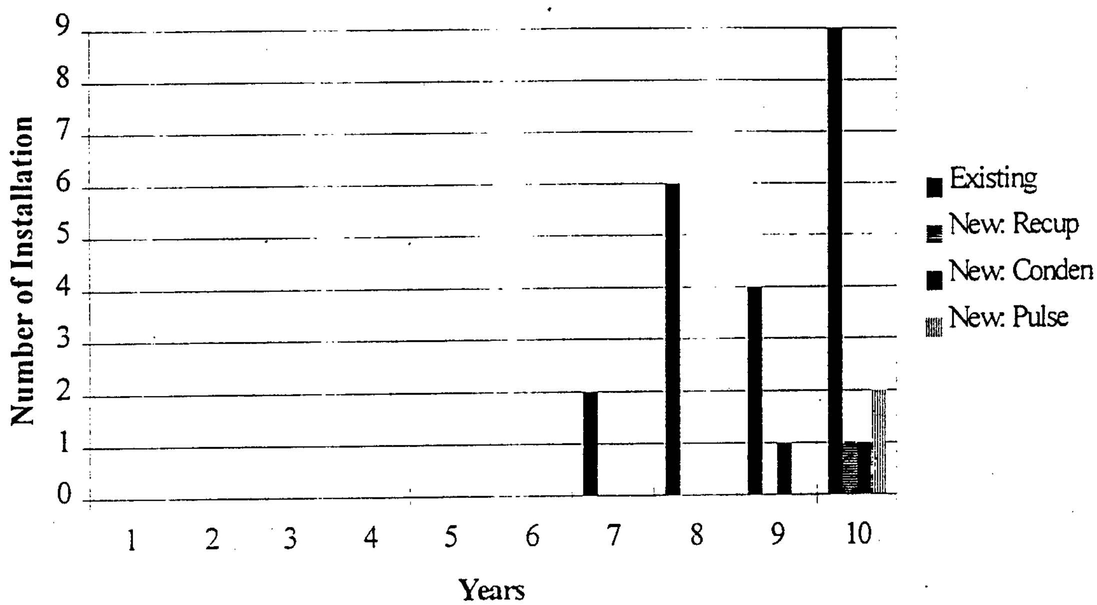

Figure A4. Simple payback distribution: high-efficiency gas furnaces (ECO Nos. F04 through F06).

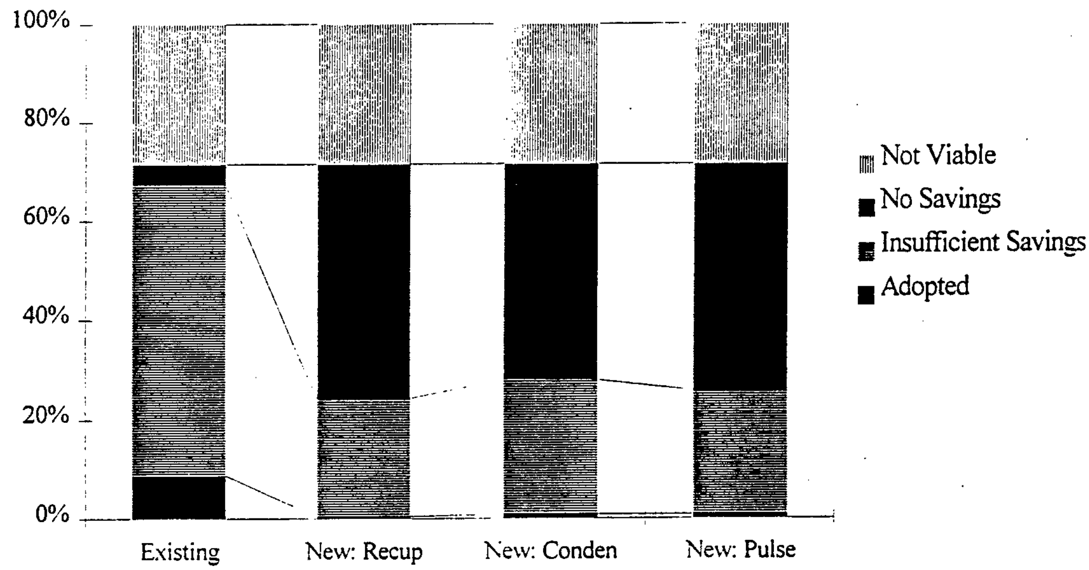

Figure A5. Base installation analysis: high-efficiency gas furnaces (ECO Nos. F04 through F06).

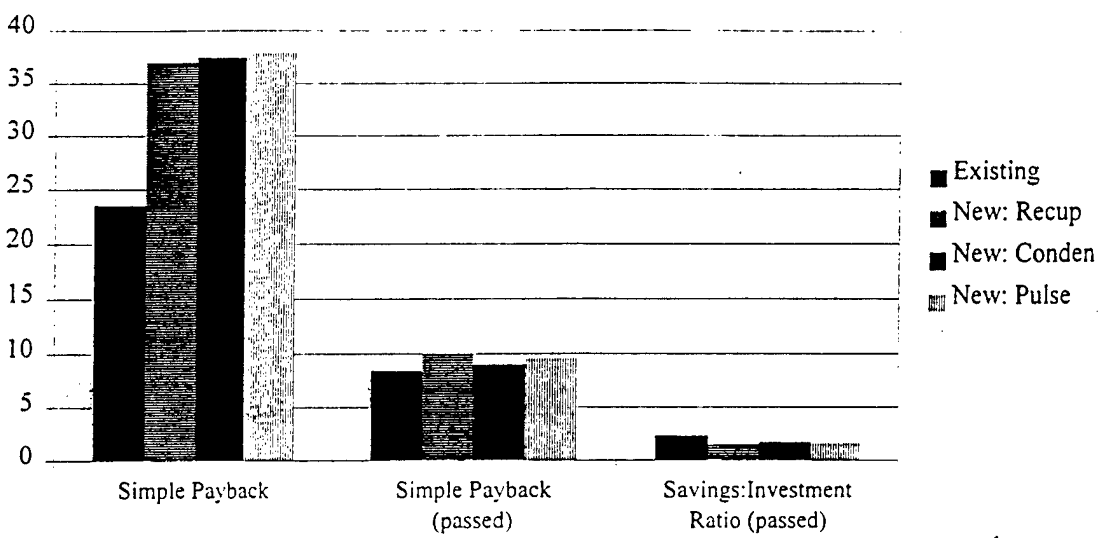

Figure A6. Average investment criteria: high-efficiency gas furnaces (ECO Nos. F04 through F06).

The final indication that the revised ECOs represent less viable technologies than the existing ECO can be seen in Figure A6. Here, payback values are higher and savings-to-investment ratios lower for the revised ECOs.

High-Efficiency Gas Boilers (ECO Nos. U16 through U18)

Figures A7 through A9 show a similar set of analysis and results for high-efficiency gas boilers (ECO Nos. U16 through U18). The new boilers are all larger than the existing ECO representation. Despite lower seasonal efficiencies, their reduced capital costs per power output level yield increased "adoptions" and decreased payback times (Figure A7).

The increase in *Adopted* installations can be seen more readily in Figure A8. The increase in boiler size is the likely cause of the shift of installations from *Insufficient Savings* to *Not Viable*.

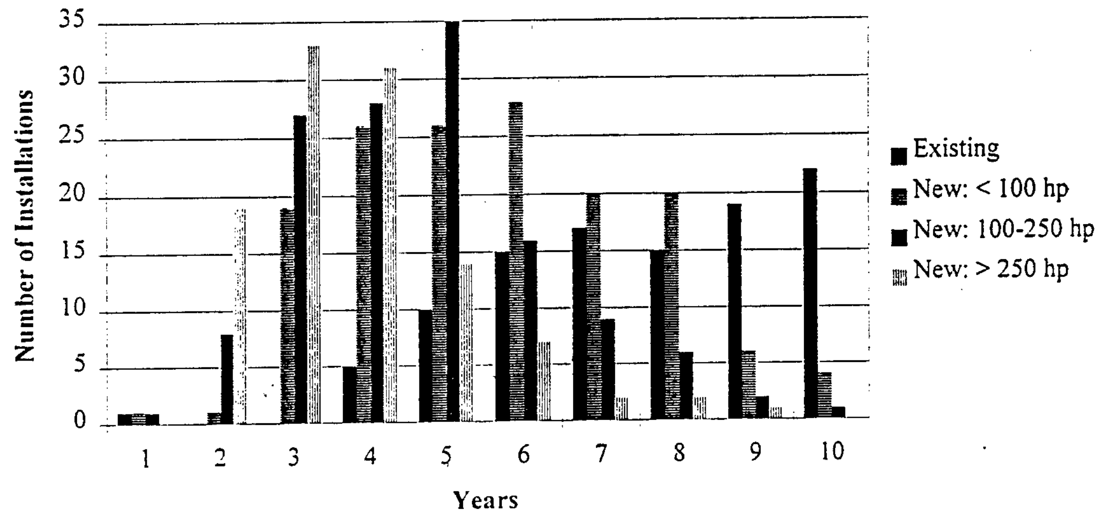

Figure A7. Simple payback distribution: high-efficiency gas boilers (ECO Nos. U16 through U18).

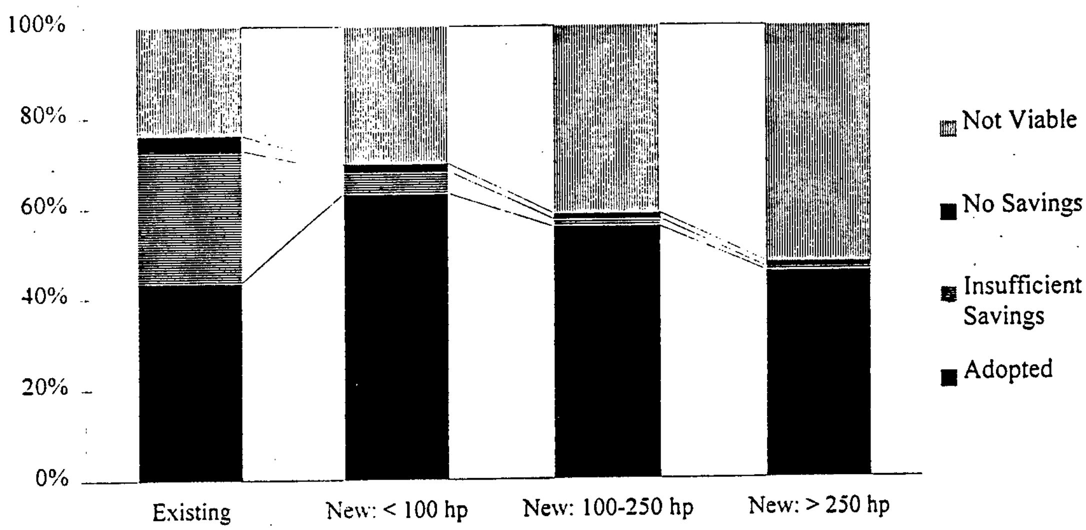

Figure A8. Base installation analysis: high-efficiency gas boilers (ECO Nos. U16 through U18).

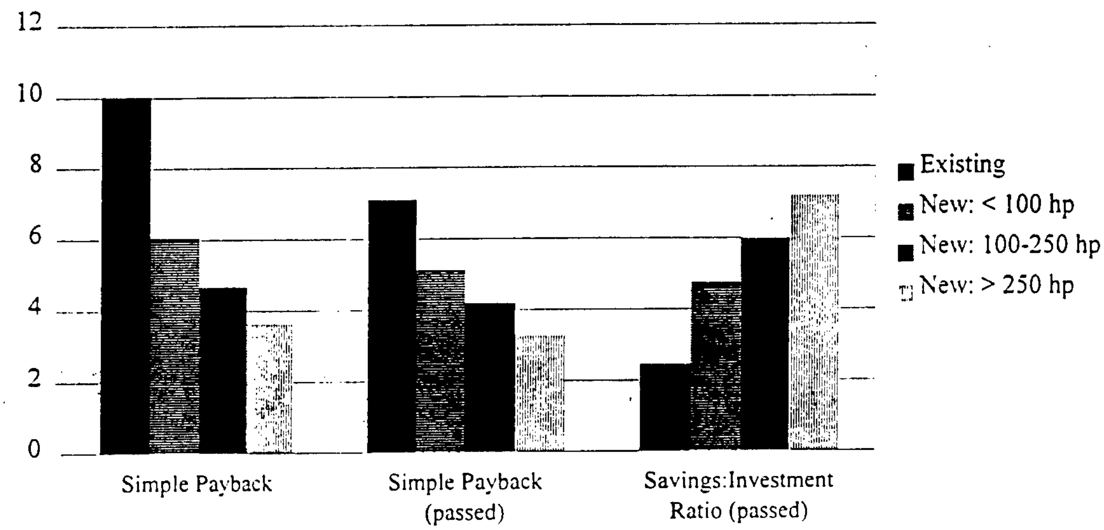

Figure A9. Average investment criteria: high-efficiency gas boilers (ECO Nos. U16 through U18).

The improved performance using the revised boiler assumptions is also seen in Figure A9. Payback times are lower and savings-to-investment ratios higher with all of the new boilers.

Cogeneration - Phosphoric Acid Fuel Cell (ECO No. U03)

Figures A10 through A12 show the analysis results for phosphoric acid fuel cell cogeneration units. There are far more *Adopted* installations for this ECO due to the initial cost reduction arising from the DOE subsidy. All other operating and cost characteristics remain the same in both cases. The increase in adoptions is also seen in Figure A11, with all new adoptions coming from the *No Savings* category.

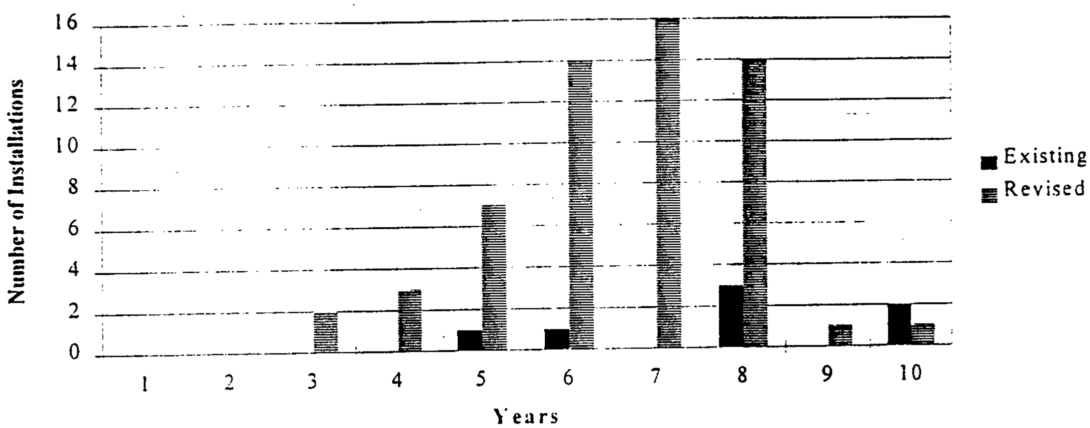

Figure A10. Simple payback distribution: cogeneration - phosphoric acid fuel cell (ECO No. U03).

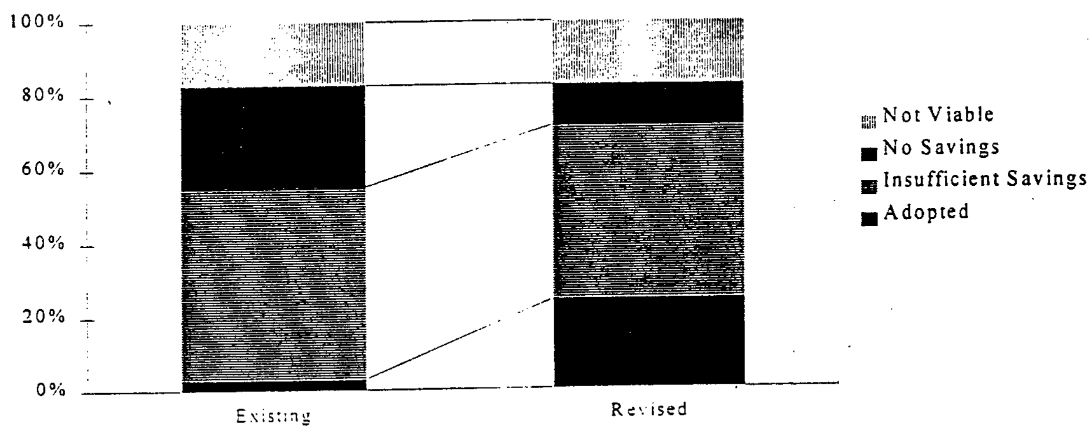

Figure A11. Base installation analysis: cogeneration - phosphoric acid fuel cell (ECO No. U03).

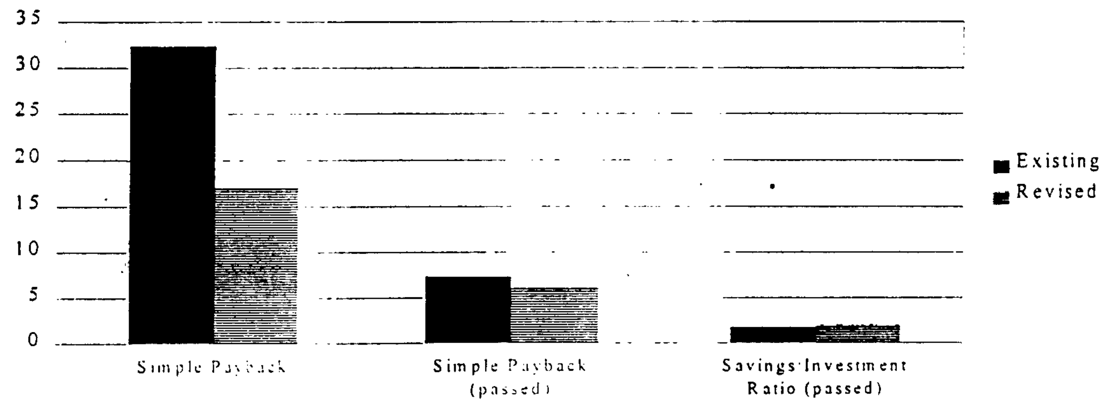

Figure A12. Average investment criteria: cogeneration - phosphoric acid fuel cell (ECO No. U03).

Although there is a significant increase in installations adopting fuel cell technology as a result of decreased initial costs, the average payback (passing) is reduced only slightly (Figure A12). Similarly, the average savings-to-investment ratio is changed upward only slightly.

Appendix B: Discussion of Cooling Season Related Data in REEP

There are several installation data elements in the current version of the REEP program that are used to calculate full load heating and/or cooling hours and, subsequently, heating and/or cooling season energy needs:

- Cooling degree days (CDD or cdd) are generally used in estimating the amount of air conditioning usage during the warm season. CDD are based on the average temperature for the day relative to 65 °F (e.g., for a day with an average temperature of 75 °F, the CDD value is 10).
- Cooling season days (cooseaday) in the installation data are calculated from long-term average weather data. Cooling season days exhibit a near-perfect correlation with CDD in the installation database.
- Summer design temperature is the one which is exceeded only 2.5 percent of the time during the cooling season.
- Full load cooling hours (fulloacoo or FLC) are calculated from CDD, and the interior and exterior design temperatures using the following relationship:

$$F_{LC} = \frac{24 \times CDD}{T_{DE} - T_{DI}}$$

where:

TDE is the exterior design temperature

TDI is the interior design temperature (78 °F).

Given that the basis of CDD is 65 °F and the denominator in the full load cooling hours calculation is referenced to 78 °F, the potential for anomalous values for full load cooling hours exists. The anomalous values are more likely to occur for locations that have summer design temperatures near the threshold of 78 °F. For example, note the data in Table B1 for Plattsburg Air Force Base in upstate New York:

Table B1. Selected Plattsburg AFB data.

Cooling degree days	341
Summer design temperature	83°F
Cooling season days	11.9
Full load cooling hours	1637
Summer dry bulb hours > 80°F	171
Summer wet bulb hours > 67°F	432

The summer design temperature of 83 °F would seem to correspond with 11.9 cooling season days (out of 122 days from June through September). Summer dry-bulb hours greater than 80 °F (171) is about 60 percent of 11.9 days x 24 hours, which also seems like a reasonable value. The value of 1637 for full load cooling hours, however, does not appear to be in line with the other data. This is probably because 1637 is derived from 341 CDD (referenced to 65 °F). If CDD were referenced to 78 °F (to correspond to the indoor design temperature), the CDD value would certainly be much smaller, yielding a correspondingly smaller full load cooling hours.

Another indication of the problematic nature of the derivation of full load cooling hours can be seen by examining the ratio of full load cooling hours to cooling season days (Figure B1). Note how nearly all of the values are greater than 24, which should be the maximum value. Compare Figure B1 to Figure B2, which shows the same ratio but for heating season parameters. Although there are some "outliers" in the heating data (those values greater than 75), most installations fall in the 8-to-12 hour range.

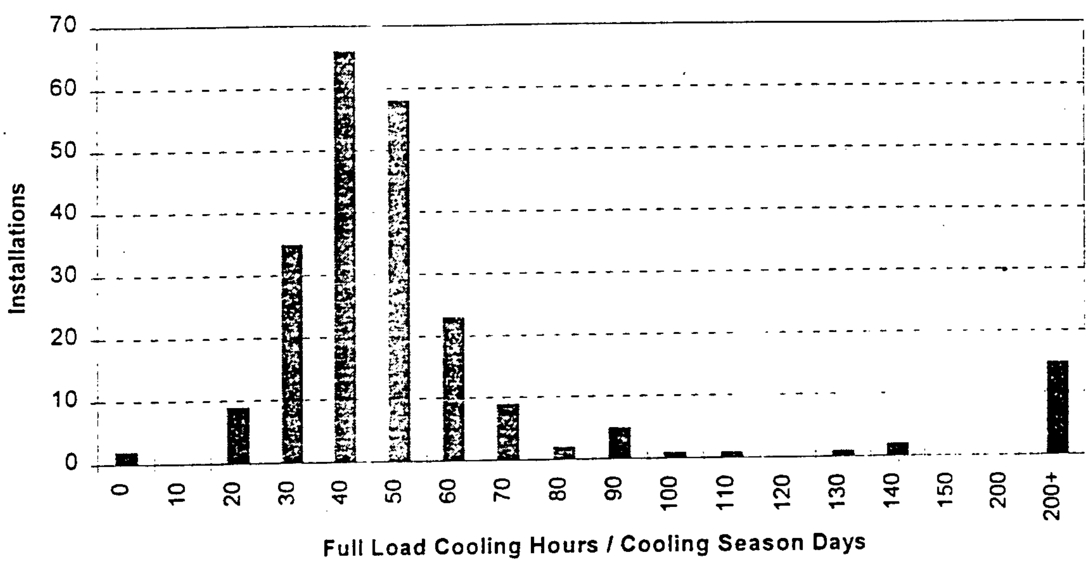

Figure B1. Distribution of full load cooling hours to cooling season days.

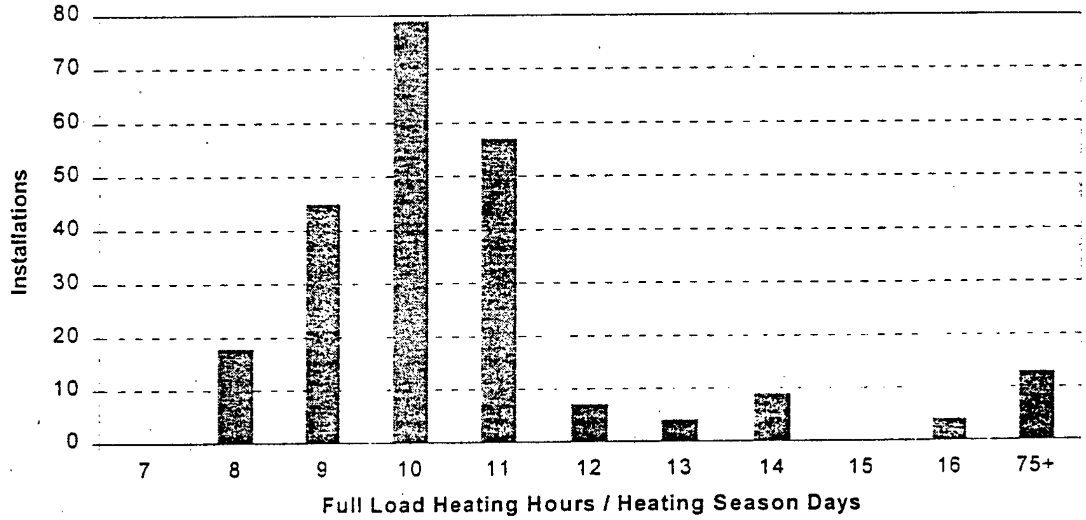

Figure B2. Distribution of full load heating hours to heating season days.

Full load cooling hours (fulloacoo or F_{LC}) is also used in the gas engine driven heat pump ECO. It is felt that Summer dry or wet bulb hours (sacdbh or sacwbh) would be more appropriate in this case. Similarly, CDD is used in the desiccant and chiller ECOs. In the desiccant ECO, CDD is used to calculate the average dry-bulb temperature during the cooling season. Despite the correlation between CDD and cooling season days, the relationship for average dry bulb temperature

$$\overline{T}_{DB} = \frac{CDD}{D_C} + 65$$

appears to yield, in at least some instances, highly erroneous results. A brief examination of about a dozen installations, all with a small number of cooling season days (D_C) yields the following:

Table B2. CDD/DC for selected REEP Installations.

Installation	City	State	CDD	Summer T_{Des}	D_c	$\frac{CDD}{D_c}$	T_{DB} Ave.	Ave. High*	Diff.
Twin Cities AAP	New Brighton	MN	527	89	20.9	25.2	90.2	81.1	9.1
Hawthorne AAP	Hawthorne	NV	487	95	19.0	25.6	90.6	91.7	-1.1
Griffiss AFB	Rome	NY	472	85	18.2	25.9	90.9	80.2	10.7
Peterson AFB	Colorado Springs	CO	461	88	17.7	26.0	91.0	89.7	1.3
Ft Drum	Watertown	NY	452	83	17.3	26.1	91.1	77.6	13.5
Tobyhanna AD	Tobyhanna	PA	434	84	16.4	26.5	91.5	82.3	9.2
Picatinny ARS	Rockaway	NJ	430	89	16.2	26.5	91.5	81.7	9.8
Oakland Hospital	East Oakland	CA	420	88	15.7	26.8	91.8	73.8	18.0
Fairchild AFB	Spokane	WA	416	90	15.5	26.8	91.8	80.0	11.8
Grand Forks AFB	Emerado	ND	400	87	14.8	27.0	92.0	77.7	14.3
Minot AFB	Minot	ND	398	89	14.7	27.1	92.1	80.6	11.5
New London	New London	CT	376	85	13.6	27.6	92.6	77.4	15.2
Malmstrom AFB	Great Falls	MT	370	88	13.3	27.8	92.8	77.6	15.2
Plattsburg AFB	Plattsburg	NY	341	83	11.9	28.7	93.7	79.2	14.5
Sierra Army Depot	Herlong	CA	329	93	11.3	29.1	94.1	86.2	7.9
Warren AFB	Cheyenne	WY	327	86	11.2	29.2	94.2	84.6	9.6
Brunswick	Brunswick	ME	308	81	10.3	29.9	94.9	76.8	18.1

* Source: U.S. Historical Climatology Network (rev. 3): Monthly Mean Maximum Temperature for June through August.

The installations in Table B2 are listed in descending order by cooling season days. The calculated dry-bulb temperatures, T_{DB}, are generally higher than the summer design temperatures (T_{Des}) and the average summer high temperatures obtained from the U.S. Historical Climatology Network. The final column is the difference between the calculated dry-bulb temperature and the average summer high temperature.

The "calculated" cooling hours, presented in the modified chiller relationships above, do not appear to be a reasonable element of cooling load. Figure B3 shows calculated cooling hours and summer dry bulb hours above 80 °F ($H_{DB>80}$) plotted against full load cooling hours. The majority of calculated hour values are greater than their corresponding full load cooling hour values. We already have reason to believe that full load cooling hours are too high. $H_{DB>80}$ values are generally lower than full load cooling hours. Unfortunately, because full load cooling hours are likely high, it is difficult to say anything definitive about the adequacy of $H_{DB>80}$. Generally, one would expect that full load cooling hours would be less than $H_{DB>80}$. Given the cooling threshold of 78 °F, $H_{DB>80}$ should be a reasonable representation of total cooling hours, but many of those hours would be at less-than-full load.

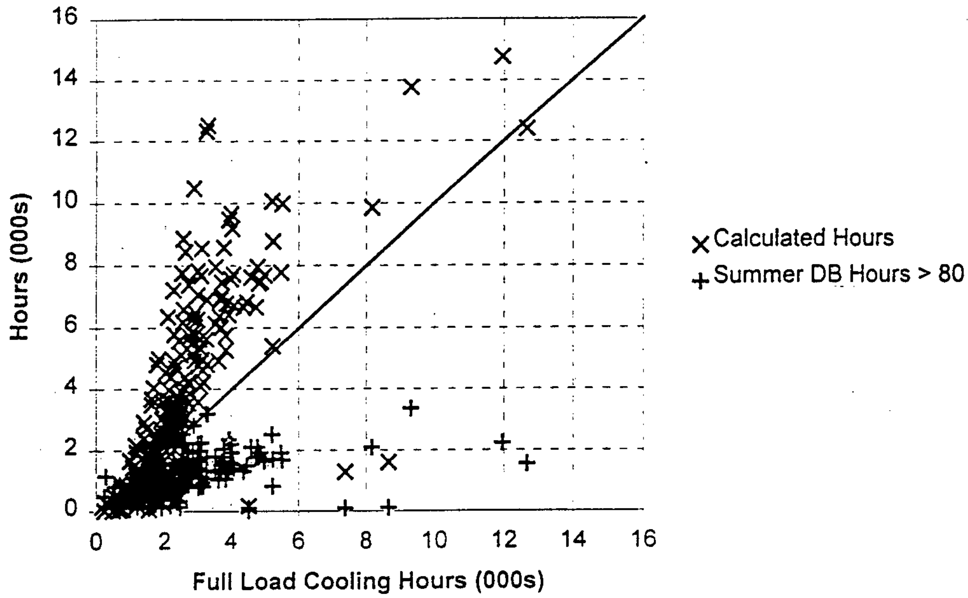

Figure B3. Comparison of cooling hours.

Summer dry bulb hours above 80 °F are used in the desiccant and enthalpy wheel ECOs. In the desiccant ECO algorithm, $H_{DB>80}$ is used in the calculation of cooling energy saved, electric energy saved, and gas energy consumed. In the enthalpy wheel ECO algorithm, this parameter is used in calculating cooling energy saved.

Appendix C: Current REEP ECO Algorithms

The Table C1 lists current ECO categories and names and their associated suggested ECO numbers as specified in Table 8. The algorithms for each of the current ECOs comprise the remainder of Appendix C. The algorithms presented herein are for reference only and, as such, have **not** been modified from those currently in the REEP program. Please refer to individual ECO descriptions in Chapter 5 for suggested algorithm changes.

Table C1. Current REEP ECOs related to suggested ECO numbers.

Current ECO Category	Current ECO Name	Applicable Suggested ECO Numbers
Heating/Cooling	Desiccant Cooling	F01, B01, B02, B03
	Enthalpy Recovery Desiccant Wheel	F02, B04, B05, B06
	Family Housing Gas Engine Driven Heat Pump	F03
	Family Housing High Efficiency Gas Furnace	F04, F05, F06
	Gas High Efficiency Boilers	U16, U17, U18
Utilities	Cogeneration—Fuel Cell	U03
	Cogeneration—Gas Turbine	U01, U02
	Cogeneration—Reciprocating Engine	U04, U05, U06, U07
	Direct Fired Natural Gas Chillers (5-50 Tons)	U08, U09
	Direct Fired Natural Gas Chillers (50-100 Tons)	U10
	Direct Fired Natural Gas Chillers (>100 Tons)	U11
	Gas Engine Air Compressors	U12
	Gas Engine Chillers (5-50 Tons)	U13
	Gas Engine Chillers (50-100 Tons)	U14
	Gas Engine Chillers (>100 Tons)	U15

```
Current ECO Category:          Heating/Cooling
Current ECO Name:          Desiccant Cooling
Applicable Suggested ECO Numbers:   F01   Desiccant Cooling -
Dehumidification System (< 5 RT)
B01   Desiccant Cooling - Dehumidification System (5 to 25 RT)
B02   Desiccant Cooling - Dehumidification System (25 to 100 RT)
B03   Desiccant Cooling - Dehumidification System (> 100 RT)

* This is the desicool.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********* calculation of W (absolute humidity ratio) ********
********* to determine the enthalpy content of ***********
********* otdoor makeup air stream, by location.***********
      ********* See ASHRAE Fundamentals 1993 6.13
*******************************************
         *** calculate atmosheric pressure [psia] based on elevation
***
            Patm = 100.000
         Patm = ( -0.000486333 * xele ) + 14.696
         *** average the mean wet-bulb temps from the 80-84 and 85-
89 bins, convert to Rankine ***
            Twb = 100.00
            Twb = ( ( xmcwb8084 + xmcwb8589 ) / 2 ) + 459.67
         *** convert the average dry-bulb temp from the 80-84 and
85-89 bins to Rankine ***
            Tdb = 100.00
            Tdb = 84.5 + 459.67
         *** calculate Pws(t*) [psia] ***
            Pwstwb = 1.0000000
            Pwstwb = EXP ( ( -10440.39708 / Twb ) - 11.2946496 - (
0.027022355 * Twb ) + ;
                      ( 0.00001289036 * Twb^2 ) - (
0.000000002478068 * Twb^3 ) + ;
                      ( 6.5459673 * LOG ( Twb ) ) )
         *** calculate Ws* ***
            Wswb = 1.0000000
            Wswb = ( 0.62189 * ( Pwstwb / ( Patm - Pwstwb ) ) )
         *** calculate W  ***
            W = 1.0000000
            W = ( ( ( 1093 - 0.556 * Twb ) * Wswb - 0.24 * ( Tdb -
Twb ) ) / ;
                 ( 1093 + ( 0.444 * Tdb ) - Twb ) )
   *** calculate the average drybulb temp during the cooling season
***
       Tdbav = 1.00000
       if xcooseaday < 10.0
       Tdbav = 0.0
```

```
        W = 0.0
        else
        Tdbav = ( xcdd / xcooseaday ) + 65
        endif
    *** calculate the total enthalpy of the ouside airstream [Btu/lb]
***
    *** This assumes the absolute humidity is same at Tdb=84.5 and
Tdb = Tdbav ***
        hin = 1.00000
        hin = ( .240 * Tdbav ) + W * ( 1061 + 0.444 * Tdbav )
    *** re-calculate the enthalpy of the airstream in [MBtu/hr*AHU]
***
    *** [MBtu/hr*AHU] = [cfm/AHU] * [min/hr] * [Btu/lb] * [lb/ft3]
***
        hin2 = xassum11v * 60 * hin * .075 / 1000000
    *** calculate enthalpy of airstream after passing through
desiccant ***
    *** this assumes space conditions of T=75F and RH=45%, assumes no
***
    *** drying by cooling coil, and no temp drop across desiccant
[Btu/lb] ***
    *** OR hout = 28 by manufacturer's literature, makes even
worse***
        hout = .24089 * Tdbav + 2.122
    *** re-calculate the enthalpy of the airstream in [MBtu/hr*AHU]
***
    *** [MBtu/hr*AHU] = [cfm/AHU] * [min/hr] * [Btu/lb] * [lb/ft3]
***
        hout2 = xassum11v * 60 * hout * .075 / 1000000
    *** calculate the enthalpy difference across desiccant
[Mbtu/hr*AHU] ***
        deltah = hin2 - hout2
********** calculate number of ECO units **********
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck > 0 .and. xaclogtst = 1
replace numecouni ;
   with ( 2 * xassum02v / 100 * xtraare / 22 ) + ( 3 * ;
        xassum04v / 100 * xrdtare / 36 ) + ( xassum03v ;
        / 100 * xhosmedare / 16 ) + ( 1.25 * xassum06v ;
        / 100 * xadmare / 15 ) + ( 3 * xassum01v / 100 ;
        * xbarare / 45.6 ) + ( xassum05v / 100 * ;
        xcomfacare / 10.2 ) * ( 1 - penfac ) * ( ;
        xassum12v / 100 )
else
replace numecouni ;
   with 0
endif
* numecouni end
**********Select Project Size Factor*************
```

```
do comcalc0
**********Calculate adjusted initial cost********
* inicos start
replace inicos ;
   with numecouni * xlocind * xcapcost * prosizfac
* inicos end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
if xaclogtst = 1
   replace cooenesav ;
      with deltah * xsacdbh * numecouni
else
   replace cooenesav ;
      with 0
endif
* cooenesav end
********** calculate electric fuel saved **********
* eleenesav start
replace eleenesav ;
   with ( cooenesav / xassum07v ) - ( xassum09v * ;
         3.412 / 1000 * xsacdbh * numecouni)
* eleenesav end
*********Calculate baseload demand saved***********
* basdemsav start
replace basdemsav ;
 with 0
* basdemsav end
*********Calculate summer demand saved*************
* sumdemsav start
   replace sumdemsav ;
     with  numecouni * xassum08v * ( ( deltah ;
     * 1000 * .29307  / xassum07v ) - xassum09v )
* sumdemsav end
********** calculate gas fuel saved **********
* gasenesav start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0
  replace gasenesav ;
     with 0
else
  replace gasenesav ;
     with -1 * xassum13v * xsacdbh * numecouni
```

```
endif
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
  replace oilenesav ;
     with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
  replace coaenesav ;
     with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with 0
* watvolsav end
**********Calculate Lbs. of CFC's displaced**************
* cfcdisp start
replace cfcdisp ;
 with 0
* cfcdisp end
* SECTION 2 - Common and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
   with 0
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations
```

```
Current ECO Category:          Heating/Cooling
Current ECO Name:           Enthalpy Recovery Desiccant Wheel
Applicable Suggested ECO Numbers:   F02   Desiccant Cooling -
Sensible and Latent Cooling (< 5 RT)
B04   Desiccant Cooling - Sensible and Latent Cooling (5 to 25 RT)
B05   Desiccant Cooling - Sensible and Latent Cooling (25-100 RT)
B06   Desiccant Enthalpy Recovery Wheel (5 to 25 RT)
```

```
* This is the enthalpy.prg program
```

```
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********* THIS ANALYSIS IS ADAPTED FROM THE VENTILATION HEAT
RECOVERY ANALYSIS **********
********* calculation of W (absolute humidity ratio) ********
********* to determine the latent heat content of ***********
********* the ventilation air stream, by location.***********
      ********* See ASHRAE Fundamentals 1989 6.13
****************************************
         *** calculate atmosheric pressure [psia] based on elevation
***
            Patm = 100.000
         Patm = ( -0.000486333 * xele ) + 14.696
         *** average the mean wet-bulb temps from the 80-84 and 85-
89 bins, convert to Rankine ***
            Twb = 100.00
            Twb = ( ( xmcwb8084 + xmcwb8589 ) / 2 ) + 459.67
         *** convert the average dry-bulb temp from the 80-84 and
85-89 bins to Rankine ***
            Tdb = 100.00
            Tdb = 84.5 + 459.67
         *** calculate Pws(t*) [psia] ***
            Pwstwb = 1.0000000
            Pwstwb = EXP ( ( -10440.39708 / Twb ) - 11.2946496 - (
0.027022355 * Twb ) + ;
                      ( 0.00001289036 * Twb^2 ) - (
0.000000002478068 * Twb^3 ) + ;
                      ( 6.5459673 * LOG ( Twb ) ) )
         *** calculate Ws* ***
            Wswb = 1.0000000
            Wswb = ( 0.62189 * ( Pwstwb / ( Patm - Pwstwb ) ) )
         *** calculate W  ***
            W = 1.0000000
            W = ( ( ( 1093 - 0.556 * Twb ) * Wswb - 0.24 * ( Tdb -
Twb ) ) / ;
                 ( 1093 + ( 0.444 * Tdb ) - Twb ) )
*******Calculate the sensible heat content of the vent airstream in
[MBtu/day*F*kft2] ******
*******     [MBtu/day*F*Kft2] = [cfm/Kft2] * [min/day] * [Btu/lb*F]
* [lb/ft3]
            Hdotsens = (xassum11v * (1440) * (.24) * (.075)) /
1000000
*******Calculate the sensible heat content of the vent airstream in
[MBtu/hr*F*kft2] ******
*******     [MBtu/hr*F*Kft2] = [cfm/Kft2] * [min/hr] * [Btu/lb*F] *
[lb/ft3]
            Hdotsenshr = Hdotsens / 24
*******Calculate the latent heat content of the vent airstream in
[MBtu/hr*F*kft2] ******
```

```
*******     [MBtu/hr*F*Kft2] = [cfm/Kft2]air * [min/hr] *
[Btu/lb*F]h2o * W * [lb/ft3]air
            Hdotlathr = (xassum11v * (60) * (.445) * W * (.075)) /
1000000
*******Calculate the Unit Demand (Btu/hr*Kft2]*********************
*[Btu/hr*Kft2] = ([cfm/Kft2] * (min/hr) * rhoAir[lb/ft3] *
deltaT[F])*(Cpair[Btu/lbF] + W[lbh20/lbair]*Cph2o)
      Udem = (xassum11v * 60 * .075 * 5 * (.24 + (.445 * W)))
********** calculate number of ECO units **********
* numecouni start
replace numecouni ;
   with ( 2 * xassum02v / 100 * xtraare / 22 ) + ( 3 * ;
        xassum04v / 100 * xrdtare / 36 ) + ( xassum03v ;
        / 100 * xhosmedare / 16 ) + ( 1.25 * xassum06v ;
        / 100 * xadmare / 15 ) + ( 3 * xassum01v / 100 ;
        * xbarare / 45.6 ) + ( xassum05v / 100 * ;
        xcomfacare / 10.2 ) * ( 1 - penfac ) * xassum12v
* numecouni end
**********Select Project Size Factor*************
do comcalc0
**********Calculate adjusted initial cost********
* inicos start
replace inicos ;
   with numecouni * xlocind * xcapcost * prosizfac
* inicos end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with xassum08v / 100 * Hdotsens *  ( 68 * ;
         xheaseaday - xhdd ) * ( ( ( xassum02v / 100) * ;
         (  xassum10v / 24) * xtraare ) + ( ( xassum04v ;
         / 100 ) * ( xassum10v / 24 ) * xrdtare ) + ;
         ( ( xassum03v / 100 ) * xhosmedare ) + ;
         ( ( xassum06v / 100 ) * ( xassum10v / 24 ) * ;
         xadmare ) + ( ( xassum01v / 100 ) * ( xassum10v ;
         / 24 ) * xbarare ) + ( xassum05v / 100 * ;
         ( xassum10v / 24 ) * xcomfacare ) ) * ;
         ( 1 - penfac )
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
if xaclogtst = 1
   replace cooenesav ;
      with Hdotsenshr * 5 * xassum08v / 100 * xsacdbh * ( ( ;
           xassum02v / 100 * xtraare ) + ( xassum04v / ;
           100 * xrdtare ) + ( xassum03v / 100 * ;
           xhosmedare ) + ( xassum06v / 100 * xadmare ;
           ) + ( xassum01v / 100 * xbarare ) + ( ;
```

```
           xassum05v / 100 * xcomfacare ) ) + ;
           Hdotlathr * 5 * xassum09v / 100 * xsacdbh * ( ( ;
           xassum02v / 100 * xtraare ) + ( xassum04v / ;
           100 * xrdtare ) + ( xassum03v / 100 * ;
           xhosmedare ) + ( xassum06v / 100 * xadmare ;
           ) + ( xassum01v / 100 * xbarare ) + ( ;
           xassum05v / 100 * xcomfacare ) )  * ( 1 - penfac )
else
   replace cooenesav ;
      with 0
endif
* cooenesav end
********** calculate electric fuel saved **********
* eleenesav start
replace eleenesav ;
   with cooenesav / xassum07v
* eleenesav end
*********Calculate baseload demand saved***********
* basdemsav start
replace basdemsav ;
 with 0
* basdemsav end
*********Calculate summer demand saved*************
* sumdemsav start
   replace sumdemsav ;
     with Udem * 1.5 * numecouni * 1 / 12000
* sumdemsav end
********** calculate gas fuel saved **********
* gasenesav start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0
  replace gasenesav ;
     with 0
else
  replace gasenesav ;
     with ( xghp35con + xghp7535con + xghp75con ) ;
          * xgascomeff ;
          / ( ( ( xghp35con + xghp7535con + xghp75con ) ;
          * xgascomeff ) ;
          + ( ( xohp35con + xohp7535con + xohp75con ) ;
          * xoilcomeff ) ;
          + ( ( xchp35con + xchp7535con + xchp75con ) ;
          * xcoacomeff ) ) ;
          * heaenesav / ( xgascomeff / 100 )
endif
* gasenesav end
********** calculate oil fuel saved **********
```

```
* oilenesav start
zcheck = xohp35con + xohp7535con + xohp75con
if zcheck = 0
  replace oilenesav ;
     with 0
else
  replace oilenesav ;
     with ( xohp35con + xohp7535con + xohp75con ) ;
          * xoilcomeff ;
          / ( ( ( xghp35con + xghp7535con + xghp75con ) ;
          * xgascomeff ) ;
          + ( ( xohp35con + xohp7535con + xohp75con ) ;
          * xoilcomeff ) ;
          + ( ( xchp35con + xchp7535con + xchp75con ) ;
          * xcoacomeff ) ) ;
          * heaenesav / ( xoilcomeff / 100 )
endif
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
zcheck = xchp35con + xchp7535con + xchp75con
if zcheck = 0
  replace coaenesav ;
     with 0
else
  replace coaenesav ;
     with ( xchp35con + xchp7535con + xchp75con ) ;
          * xcoacomeff ;
          / ( ( ( xghp35con + xghp7535con + xghp75con ) ;
          * xgascomeff ) ;
          + ( ( xohp35con + xohp7535con + xohp75con ) ;
          * xoilcomeff ) ;
          + ( ( xchp35con + xchp7535con + xchp75con ) ;
          * xcoacomeff ) ) ;
          * heaenesav / ( xcoacomeff / 100 )
endif
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with 0
* watvolsav end
**********Calculate Lbs. of CFC's displaced**************
* cfcdisp start
replace cfcdisp ;
 with 0
* cfcdisp end
```

```
* SECTION 2 - Common and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
   with 0
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations

Current ECO Category:          Heating/Cooling
Current ECO Name:           Family Housing Gas Engine Driven Heat
Pump
Applicable Suggested ECO Number: F03   Gas-Engine-Driven Heat Pump

* This is the gasengif.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units ************
* numecouni start
if xassum01v = 0
   replace numecouni ;
      with 0
else
   if xaclogtst = 1
      replace numecouni ;
         with xfamhouare / xassum01v * ( 1 - penfac )
   else
      replace numecouni ;
         with 0
   endif
endif
* numecouni end
**********Select Project Size Factor**********
do comcalc0
**********Calculate Adjusted Initial Cost********
* inicos start
replace inicos ;
   with numecouni * xlocind * xcapcost * prosizfac
* inicos end
```

```
********* calculate heating energy saved***********
* heaenesav start
replace heaenesav ;
   with xfuloheafh * numecouni * ( xassum03v / 1000000 )
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with xfulloacoo * numecouni * .03
* cooenesav end
********** calculate electric fuel saved ***********
* eleenesav start
replace eleenesav ;
   with cooenesav / ( xassum05v / 3.412 )
* eleenesav end
********** calculate base load fuel saved **********
* basdemsav start
replace basdemsav ;
   with 0
* basdemsav end
******** calculate summer demand fuel saved*******
* sumdemsav start
replace sumdemsav ;
   with xassum06v * numecouni * .9
* sumdemsav end
********** calculate gas fuel saved ***********
* gasenesav start
replace gasenesav ;
   with ( heaenesav / ( xassum02v / 100 ) ) - ( ;
        heaenesav / ( xassum09v / 100 ) ) - ( cooenesav ;
        / xassum07v )
* gasenesav end
*********** calculate oil fuel saved ***********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
*********** calculate coal fuel saved ***********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with 0
* watvolsav end
```

```
*********** Calculate Lbs. of CFCs displaced *************
* cfcdisp start
replace cfcdisp ;
   with 0
* cfcdisp end
* SECTION 2 - Common and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
   with 0
* watcossav end
*********** calculate HVAC energy cost saved ***********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations

Current ECO Category:          Heating/Cooling
Current ECO Name:           Family Housing High Efficiency Gas
Furnace
Applicable Suggested ECO Numbers:   F04   High-Efficiency Gas
Furnace, Recuperative
F05   High-Efficiency Gas Furnace, Condensing
F06   High-Efficiency Gas Furnace, Pulse Combustion

* This is the gasfurnf.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
* numecouni start
if xghp75con > 0 and xaclogtst = 1
   replace numecouni ;
      with ( 1 - penfac ) * xghp75con / ( xghp75con ;
            + xohp75con + xchp75con ) * xfamhouare ;
            / xassum01v
else
   if xghp75cap > 0 and xaclogtst = 1
      replace numecouni ;
         with ( 1 - penfac ) * xghp75cap / ( xghp75cap ;
               + xohp75cap + xchp75cap ) * xfamhouare ;
               / xassum01v
   else
      if xghp75con > 0 and xaclogtst = 0
```

```
            replace numecouni ;
                  with ( 1 - penfac ) * xghp75con / ;
                      ( xghp75con + xohp75con + xchp75con ) ;
                      * xfamhouare / xassum01v * .5
         else
            if xghp75cap > 0 and xaclogtst = 0
               replace numecouni ;
                     with ( 1 - penfac ) * xghp75cap / ;
                         ( xghp75cap + xohp75cap + ;
                         xchp75cap ) * xfamhouare ;
                         / xassum01v * .5
               else
                  replace numecouni ;
                        with 0
            endif
         endif
      endif
   endif
   * numecouni end
   ********** Select Project Size Factor ******
   do comcalc0
   ********** calculate initial cost **********
   * inicos start
   replace inicos ;
      with xlocind * numecouni * xcapcost * prosizfac
   * inicos end
   ********** calculate heating energy saved **********
   * heaenesav start
   replace heaenesav ;
      with ( 1 - ( xassum02v / xassum03v ) ) * xhdd * 16.5 ;
           * numecouni * xassum01v / 1000
   * heaenesav end
   ********** calculate cooling energy saved **********
   * cooenesav start
   replace cooenesav ;
       with 0
   * cooenesav end
   ********** calculate electric fuel saved **********
   * eleenesav start
   replace eleenesav ;
      with xhdd * ( -xassum04v ) * 3.412 / 1000 * numecouni
   * eleenesav end
   ********** calculate baseload demand saved **********
   * basdemsav start
   replace basdemsav ;
      with 0
   * basdemsav end
```

```
********** calculate summer demand saved **********
* sumdemsav start
replace sumdemsav ;
  with 0
* sumdemsav end
********** calculate gas fuel saved **********
* gasenesav start
replace gasenesav ;
   with heaenesav
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water volume saved **********
* watvolsav start
replace watvolsav ;
   with 0
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with 0
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
   with 0
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations

Current ECO Category:         Heating/Cooling
```

Current ECO Name: Gas High Efficiency Boilers

Applicable Suggested ECO Numbers: U16 High-Efficiency Gas Boiler (< 100 hp)

U17 High-Efficiency Gas Boiler (100 to 250 hp)

U18 High-Efficiency Gas Boiler (> 250 hp)

```
* This is the pulscomb.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
* numecouni start
if xfulloahea = 0
   replace numecouni ;
      with 0
else
   replace numecouni ;
      with ( 1 - penfac ) * ( ( ( xghp7535con * xassum04v ;
           / 100 + xghp75con * xassum03v / 100 ) * ( ;
           xassum06v / 100 ) / (xassum02v * xfulloahea ) + ;
           ( ( xghp7535cap * xassum04v / 100 + ;
           xghp75cap * xassum03v / 100 ) * 2 / ;
           xassum01v ) ) ) / 2
endif
* numecouni end
********** Select Project Size Factor *************
do comcalc0
********** Calculate adjusted initial cost **********
* inicos start
replace inicos ;
   with numecouni * xlocind * xcapcost * prosizfac
* inicos end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with numecouni * xassum02v * xfulloahea * ;
      ( ( 100 / xassum06v ) - ( 100 / xassum05v ) )
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate baseload demand saved **********
* basdemsav start
replace basdemsav ;
   with 0
```

```
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
replace sumdemsav ;
   with 0
* sumdemsav end
********** calculate electric fuel saved **********
* eleenesav start
replace eleenesav ;
   with 0
* eleenesav end
********** calculate gas fuel saved **********
* gasenesav start
  replace gasenesav ;
     with heaenesav
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
  replace oilenesav ;
     with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
  replace coaenesav ;
     with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with 0
* watvolsav end
********** Calculate Lbs. of CFC's displaced **********
* cfcdisp start
replace cfcdisp ;
   with 0
* cfcdisp end
* SECTION 2 - Common and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
   with 0
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
```

```
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations

Current ECO Category:          Utilities
Current ECO Name:           Cogeneration—Fuel Cell
Applicable Suggested ECO Number: U03   Cogeneration - Phosphoric
Acid Fuel Cell

* This is the cogencel.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
**************************************************
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
demandcheck = .33 * xelekwpdem / 1000 / .2
electcheck = .33 * xeleserq / xassum02v / .2
if zcheck = 0
  replace numecouni ;
     with 0
else
   if xhosmedare > xassum08v
     replace numecouni ;
        with ( xghp35cap ) / xassum07v + 1
     else
      replace numecouni ;
        with ( xghp35cap ) / xassum07v
     endif
     if demandcheck < numecouni
      replace numecouni ;
        with demandcheck
     endif
     if electcheck < demandcheck
      replace numecouni ;
        with electcheck
     endif
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac
```

```
* inicos end
********** calculate baseload demand saved **********
**********Contains fixed assumption KW = 200*******************
* basdemsav start
replace basdemsav ;
   with numecouni * 200 * xassum01v
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with 0
* sumdemsav end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate electric fuel saved **********
**********Contains fixed assumption KW = 200*******************
* eleenesav start
replace eleenesav ;
   with numecouni * 200 * xassum02v * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
**********Contains fixed assumption KW = 200****************
* gasenesav start
replace gasenesav ;
   with -1 *  numecouni * 200 * ( ( xassum02v ;
         * xassum03v ) - ( ( xassum04v / 100 * xassum03v ;
         * xassum05v ) / xassum06v ) ) / 1000000
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
```

```
* watvolsav start
replace watvolsav ;
   with 0
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with 0
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
    with 0
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations
```

Current ECO Category: Utilities
Current ECO Name: Cogeneration—Gas Turbine
Applicable Suggested ECO Numbers: U01 Cogeneration - Gas Turbine (< 5 MW)
U02 Cogeneration - Gas Turbine (5 to 20 MW)

```
* This is the cogentur.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
**********Contains fixed assumption*******************
* numecouni start
demandcheck = .33 * xelekwpdem / 1000 / 5
electcheck = .33 * xeleserq / xassum02v / 5
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0
  replace numecouni ;
     with 0
else
   if xhosmedare > xassum08v
      replace numecouni ;
```

```
        with ( xghp35cap ) / xassum07v + 1
    else
     replace numecouni ;
        with ( xghp35cap ) / xassum07v
    endif
    if demandcheck < numecouni
     replace numecouni ;
        with demandcheck
    endif
    if electcheck < demandcheck
     replace numecouni ;
        with electcheck
    endif
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac * 10
* inicos end
********** calculate baseload demand saved **********
**********Contains fixed assumption KW = 5000********************
* basdemsav start
replace basdemsav ;
   with numecouni * 5000 * xassum01v
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with 0
* sumdemsav end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate electric fuel saved **********
**********Contains fixed assumption KW = 5000********************
* eleenesav start
replace eleenesav ;
```

```
   with numecouni * 5000 * xassum02v * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
**********Contains fixed assumption KW = 5000*************
* gasenesav start
replace gasenesav ;
   with -1 * numecouni * 5000 * ( ( xassum02v * xassum03v ) ;
   - ( xassum04v / 100 * xassum03v * xassum05v / ;
          xassum06v ) ) / 1000000
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with 0
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with 0
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
    with 0
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations

Current ECO Category:        Utilities
```

Current ECO Name: Cogeneration—Reciprocating Engine

Applicable Suggested ECO Numbers: U04 Cogeneration - Reciprocating Engine (< 100 kW)

U05 Cogeneration - Reciprocating Engine (100 to 500 kW)

U06 Cogeneration - Reciprocating Engine (500 kW to 2 MW)

U07 Cogeneration - Reciprocating Engine (> 2 MW)

```
* This is the cogeneng.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
**********Contains fixed assumption********************
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
demandcheck = .33 * xelekwpdem / 1000 / .5
electcheck = .33 * xeleserq / xassum02v / .5
if zcheck = 0
replace numecouni ;
     with 0
else
   if xhosmedare > xassum08v
      replace numecouni ;
         with ( xghp35cap ) / xassum07v + 1
     else
      replace numecouni ;
         with ( xghp35cap ) / xassum07v
     endif
     if demandcheck < numecouni
      replace numecouni ;
      with demandcheck
     endif
     if electcheck < demandcheck
      replace numecouni ;
      with electcheck
     endif
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac
* inicos end
********** calculate baseload demand saved **********
**********Contains fixed assumption KW = 500********************
```

```
* basdemsav start
replace basdemsav ;
   with numecouni * 500 * xassum01v
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with 0
* sumdemsav end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate electric fuel saved **********
**********Contains fixed assumption KW = 500********************
* eleenesav start
replace eleenesav ;
   with numecouni * 500 * xassum02v * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
**********Contains fixed assumption KW = 500********************
* gasenesav start
replace gasenesav ;
   with -1 * numecouni * 500 * ( ( xassum02v * xassum03v ) ;
   - ( xassum04v / 100 * xassum03v * xassum05v / ;
          xassum06v ) ) / 1000000
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with 0
```

```
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with 0
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
    with 0
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations

Current ECO Category:         Utilities
Current ECO Name:          Direct Fired Natural Gas Chillers (5-50
Tons)
Applicable Suggested ECO Numbers:   U08   Direct-Fired Gas
Absorption Chiller (< 5 RT)
U09   Direct-Fired Gas Absorption Chiller (5 to 25 Tons)

* This is the childfrs.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0 .or. xsumdestem - xassum02v < 0
  replace numecouni ;
     with 0
else
  replace numecouni ;
     with ( 1 - penfac ) * xacw5100cap / xassum01v ;
           * ( xassum09v / 100 )
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
```

```
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac
* inicos end
********** calculate baseload demand saved **********
* basdemsav start
replace basdemsav ;
   with 0
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with numecouni * ( xassum05v - xassum04v ) * ;
           xassum01v * xassum08v
* sumdemsav end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate electric fuel saved **********
* eleenesav start
replace eleenesav ;
   with ( 24 * xcdd / ( xsumdestem - xassum02v ) ) * ;
        sumdemsav * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
* gasenesav start
replace gasenesav ;
   with -1 * ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ;
        * xassum01v * xassum08v * numecouni * xassum03v ;
        / 1000000
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
```

```
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with - ( xassum06v * numecouni * xassum01v * ;
           ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ) / 1000
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with xassum01v * xassum07v * numecouni
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
    with watvolsav * xwatseru
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations
```

Current ECO Category: Utilities

Current ECO Name: Direct Fired Natural Gas Chillers (50-100 Tons)

Applicable Suggested ECO Number: U10 Direct-Fired Gas Absorption Chiller (25 to 100 Tons)

```
* This is the childfrm.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0 .or. xsumdestem - xassum02v < 0
  replace numecouni ;
     with 0
else
  replace numecouni ;
     with ( 1 - penfac ) * xacw5100cap / xassum01v ;
           * ( xassum09v / 100 )
```

```
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac
* inicos end
********** calculate baseload demand saved **********
* basdemsav start
replace basdemsav ;
   with 0
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with numecouni * ( xassum05v - xassum04v ) * ;
           xassum01v * xassum08v
* sumdemsav end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate electric fuel saved **********
* eleenesav start
replace eleenesav ;
   with ( 24 * xcdd / ( xsumdestem - xassum02v ) ) * ;
        sumdemsav * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
* gasenesav start
replace gasenesav ;
   with -1 * ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ;
        * xassum01v * xassum08v * numecouni * xassum03v ;
        / 1000000
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
```

```
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with - ( xassum06v * numecouni * xassum01v * ;
          ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ) / 1000
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with xassum01v * xassum07v * numecouni
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
    with watvolsav * xwatseru
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations
```

Current ECO Category: Utilities

Current ECO Name: Direct Fired Natural Gas Chillers (>100 Tons)

Applicable Suggested ECO Number: U11 Direct-Fired Gas Absorption Chiller (>100 Tons)

```
* This is the childfrl.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0 .or. xsumdestem - xassum02v < 0
  replace numecouni ;
```

```
     with 0
else
  replace numecouni ;
     with ( 1 - penfac ) * xacw100cap / xassum01v
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac
* inicos end
********** calculate baseload demand saved **********
* basdemsav start
replace basdemsav ;
   with 0
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with numecouni * ( xassum05v - xassum04v ) * ;
           xassum01v * xassum08v
* sumdemsav end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate electric fuel saved **********
* eleenesav start
replace eleenesav ;
   with ( 24 * xcdd / ( xsumdestem - xassum02v ) ) * ;
        sumdemsav * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
* gasenesav start
replace gasenesav ;
   with -1 * ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ;
        * xassum01v * xassum08v * numecouni * xassum03v ;
        / 1000000
* gasenesav end
```

```
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with - ( xassum06v * numecouni * xassum01v * ;
          ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ) / 1000
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with xassum01v * xassum07v * numecouni
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
    with watvolsav * xwatseru
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations
```

Current ECO Category: Utilities

Current ECO Name: Gas Engine Air Compressors

Applicable Suggested ECO Number: U12 Gas Engine-Driven Air Compressor

```
* This is the gascmprs.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
```

```
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0
  replace numecouni ;
     with 0
else
   if xmac == "AMC    "
      replace numecouni ;
        with ( 1 - penfac ) * xmaiproare / 1000
    else
      replace numecouni ;
      with 0
    endif
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac
* inicos end
********** calculate baseload demand saved **********
**********Contains fixed assumption HP = 100********************
* basdemsav start
replace basdemsav ;
   with numecouni * 100 * xassum01v * 0.746 / xassum02v
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with 0
* sumdemsav end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate electric fuel saved **********
*********** Contains fixed assumption Hp = 100 ****
* eleenesav start
replace eleenesav ;
```

```
   with numecouni * 100 * 0.746 / ;
        xassum02v * xassum03v * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
**********Contains fixed assumption HP =100 **
* gasenesav start
replace gasenesav ;
   with -1 * numecouni * 100 * xassum04v * xassum03v / 1000000
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with 0
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with 0
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
    with 0
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations

Current ECO Category:          Utilities
Current ECO Name:           Gas Engine Chillers (5-50 Tons)
```

Applicable Suggested ECO Number: U13 Gas Engine-Driven Chiller (5 to 25 Tons)

```
* This is the chilgass.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0 .or. xsumdestem - xassum02v < 0
  replace numecouni ;
     with 0
else
  replace numecouni ;
     with ( 1 - penfac ) * xacw5100cap / xassum01v ;
            * ( xassum09v / 100 )
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac
* inicos end
********** calculate baseload demand saved **********
* basdemsav start
replace basdemsav ;
   with 0
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with numecouni * ( xassum05v - xassum04v ) * ;
           xassum01v * xassum08v
* sumdemsav end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
```

```
********** calculate electric fuel saved **********
* eleenesav start
replace eleenesav ;
   with ( 24 * xcdd / ( xsumdestem - xassum02v ) ) * ;
        sumdemsav * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
* gasenesav start
replace gasenesav ;
   with -1 * ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ;
        * xassum01v * xassum08v * numecouni * xassum03v ;
        / 1000000
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with - ( xassum06v * numecouni * xassum01v * ;
          ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ) / 1000
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with xassum07v * xassum01v * numecouni
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
    with watvolsav * xwatseru
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
```

```
* SECTION 3 - ECO specific calculations that override common
calculations

Current ECO Category:         Utilities
Current ECO Name:          Gas Engine Chillers (50-100 Tons)
Applicable Suggested ECO Number: U14   Gas Engine-Driven Chiller (25
to 100 Tons)

* This is the chilgasm.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0 .or. xsumdestem - xassum02v < 0
  replace numecouni ;
     with 0
else
  replace numecouni ;
     with ( 1 - penfac ) * xacw5100cap/ xassum01v ;
           * ( xassum09v / 100 )
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac
* inicos end
********** calculate baseload demand saved **********
* basdemsav start
replace basdemsav ;
   with 0
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with numecouni * ( xassum05v - xassum04v ) * ;
           xassum01v * xassum08v
* sumdemsav end
********** calculate heating energy saved **********
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
```

```
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate electric fuel saved **********
* eleenesav start
replace eleenesav ;
   with ( 24 * xcdd / ( xsumdestem - xassum02v ) ) * ;
         sumdemsav * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
* gasenesav start
replace gasenesav ;
   with -1 * ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ;
         * xassum01v * xassum08v * numecouni * xassum03v ;
         / 1000000
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with - ( xassum06v * numecouni * xassum01v * ;
           ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ) / 1000
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with xassum07v * xassum01v * numecouni
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
replace watcossav ;
    with watvolsav * xwatseru
* watcossav end
********** calculate HVAC energy cost saved **********
```

```
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations
```

Current ECO Category: Utilities

Current ECO Name: Gas Engine Chillers (>100 Tons)

Applicable Suggested ECO Number: U15 Gas Engine-Driven Chiller (>100 Tons)

```
* This is the chilgasl.prg program
* SECTION 1 - ECO specific calculations
********** Select the Penetration Factor **********
do comcalc
********** calculate number of ECO units **********
* numecouni start
zcheck = xghp35con + xghp7535con + xghp75con
if zcheck = 0 .or. xsumdestem - xassum02v < 0
  replace numecouni ;
     with 0
else
  replace numecouni ;
     with ( 1 - penfac ) * xacw100cap / xassum01v
endif
* numecouni end
********** Select Project Size Factor ******
do comcalc0
********** calculate initial cost **********
* inicos start
replace inicos ;
   with numecouni * xcapcost * xlocind * prosizfac
* inicos end
********** calculate baseload demand saved **********
* basdemsav start
replace basdemsav ;
   with 0
* basdemsav end
********** calculate summer demand saved **********
* sumdemsav start
   replace sumdemsav ;
      with numecouni * ( xassum05v - xassum04v ) * ;
           xassum01v * xassum08v
* sumdemsav end
********** calculate heating energy saved **********
```

```
* heaenesav start
replace heaenesav ;
   with 0
* heaenesav end
********** calculate cooling energy saved **********
* cooenesav start
replace cooenesav ;
   with 0
* cooenesav end
********** calculate electric fuel saved **********
* eleenesav start
replace eleenesav ;
   with ( 24 * xcdd / ( xsumdestem - xassum02v ) ) * ;
        sumdemsav * 3.412 / 1000
* eleenesav end
********** calculate gas fuel saved **********
* gasenesav start
replace gasenesav ;
   with -1 * ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ;
        * xassum01v * xassum08v * numecouni * xassum03v ;
        / 1000000
* gasenesav end
********** calculate oil fuel saved **********
* oilenesav start
replace oilenesav ;
   with 0
* oilenesav end
********** calculate coal fuel saved **********
* coaenesav start
replace coaenesav ;
   with 0
* coaenesav end
********** calculate water saved **********
* watvolsav start
replace watvolsav ;
   with - ( xassum06v * numecouni * xassum01v * ;
          ( 24 * xcdd / ( xsumdestem - xassum02v ) ) ) / 1000
* watvolsav end
********* calculate Lbs. of CFCs displaced ***********
* cfcdisp start
replace cfcdisp ;
   with xassum07v * xassum01v * numecouni
* cfcdisp end
* SECTION 2 - Common calculations and HVAC calculations
do comcalc1
********** calculate water cost saved **********
* watcossav start
```

```
replace watcossav ;
    with watvolsav * xwatseru
* watcossav end
********** calculate HVAC energy cost saved **********
* henecossav start
replace henecossav ;
   with 0
* henecossav end
do comcalc2
* SECTION 3 - ECO specific calculations that override common
calculations
```

Appendix D: Field Visits Report

As a part of this research effort, three site visits were conducted to verify/update the installation data, to obtain information as to how each facility planner screens/evaluates/implements advanced technology, and to solicit suggestions for further enhancing the utility of the REEP program. Three sites visited were:

- Fort Eustis, VA
- Fort Hood, TX
- Fort Riley, KS.

Fort Eustis, VA

This visit was conducted on 13 September 1996. IGT personnel met with Mr. David Wood and his staff from the Directorate of Public Works (DPW). The following bullets highlight the information obtained through this visit:

- The facility has received an approval to install a 350 RT gas engine-driven chiller (TECOCHILL) to replace an old 250 RT unit at a hospital on the premises. It will offset their peak cost, remove a unit that uses an ozone-depleting refrigerant, and enable them to receive a rate advantage from the local utility.
- A 200 kW phosphoric acid fuel cell is being installed at Andersen Field House, the gymnasium.
- Process heating and space costs are billed on a sq ft basis.
- This installation has a sub-facility – Fort Story – that is managed by the U.S. Navy. Installation data for Fort Eustis does not include Fort Story.
- This installation has 968 Lennox pulse combustion furnaces, 974 electric chillers, and 6 fuel oil heaters in family housing quarters.

- They use Reflect-O-Ray radiant heaters in hanger facilities; savings of 30 percent have already been realized.
- A 3.2 MW engine-driven power generation facility is being built for peakshaving and power backup.
- The facility has 13 central heating plants, all on interruptible rate schedule. Each plant has 2 meters – one for pilot and one for actual consumption.
- They are interested in Triathlon, desiccant dehumidification system, desiccant cooling system, large-size gas engine-driven chillers, and a natural gas-fueled vehicle fueling station.
- Suggestion is to add geothermal (air-source or ground-source) heat pump ECO in the REEP program.

Table D1 shows the updated data sheet of REEP data elements for Fort Eustis, VA.

Table D1. REEP data elements for Fort Eustis, VA.

Description	Value	Units	No Revision	Revised Value
Department of Defense Service	ARMY	(none)	☑	
Installation	FT EUSTIS	(none)	☑	
Major Command	TRADOC	(none)	☑	
Population	48311	Persons	☑	
Water Service Quantity	679556	Kgal	☐	538681
Water Service Total Cost	1377001	$	☐	1233624
Water Service Unit Cost	2.03	$/Kgal	☐	2.34
Water Distribution	591	K Lin °Ft	☐	
Sewage Service Quantity	789554	Kgal	☐	532807
Sewage Service Total Cost	702079	$	☐	540215
Sewage Service Unit Cost	0.89	$/Kgal	☐	1.01
Electricity Service Quantity	125118	MWH	☐	88480
Electric Service Total Cost	5209731	$	☐	4147981
Electric Service Unit Cost	41.64	$/MWH	☐	46.88
Gas, Oil, and Coal Service Total Cost	2775007	$	☐	1972931
Building Service Quantity	10186	K Sq. Ft	☐	
Baseline (1985) Building Area	7763	KSF	☑	
Baseline (1985) Energy consumption	970599	MBtu	☑	
Gas Fired Heating Plant > 3.5 MBtu/Hr capacity	139	MBtu/Hr	☐	
Gas Fired Heating Plant > 3.5 MBtu/Hr Consumed	315488	MBtu	☐	
Oil Fired Heating Plant > 3.5 MBtu/Hr capacity	93	MBtu/Hr	☐	
Oil Fired Heating Plant > 3.5 MBtu/Hr Consumed	56548	MBtu	☐	

Description	Value	Units	No Revision	Revised Value
Coal Fired Heating Plant > 3.5 MBtu/Hr capacity	0	MBtu/Hr	☑	
Coal Fired Heating Plant > 3.5 MBtu/Hr Consumed	0	MBtu	☑	
Gas Fired Heating Plant .75 - 3.5 MBtu/Hr capacity	32	MBtu/Hr	☐	
Gas Fired Heating Plant .75 - 3.5 MBtu/Hr Consumed	16402	MBtu	☐	
Oil Fired Heating Plant .75 - 3.5 MBtu/Hr capacity	10	MBtu/Hr	☐	
Oil Fired Heating Plant .75 - 3.5 MBtu/Hr Consumed	1753	MBtu	☐	
Coal Fired Heating Plant .75 - 3.5 MBtu/Hr capacity	0	MBtu/Hr	☑	
Coal Fired Heating Plant .75 - 3.5 MBtu/Hr Consumed	0	MBtu	☑	
Gas Fired Heating Plant < .75 MBtu/Hr capacity	137	MBtu/Hr	☐	
Gas Fired Heating Plant < .75 MBtu/Hr Consumed	61633	MBtu	☐	
Oil Fired Heating Plant < .75 MBtu/Hr capacity	273	MBtu/Hr	☐	
Oil Fired Heating Plant < .75 MBtu/Hr Consumed	82404	MBtu	☐	
Coal Fired Heating Plant < .75 MBtu/Hr capacity	0	MBtu/Hr	☑	
Coal Fired Heating Plant < .75 MBtu/Hr Consumed	0	MBtu	☑	
A/C and Chilled Water Plant > 100 Tons capacity	4541	Tons	☐	
A/C and Chilled Water Plant 5 - 100 Ton capacity	4629	Tons	☐	
A/C and Chilled Water Plant < 5 Tons capacity	3968	Tons	☐	
Training Area	1942	K Sq. Ft	☐	1074
Maintenance and Production Area	861	K Sq. Ft	☐	541
Research, Development, and Testing Area	147	K Sq. Ft	☐	121
Storage Area	997	K Sq. Ft	☐	736
Hospital and Medical Area	207	K Sq. Ft	☐	187
Administrative Area	1129	K Sq. Ft	☐	687
Barracks Area	1213	K Sq. Ft	☐	996
Common Facilities Area	1011	K Sq. Ft	☐	801
Family Housing Area	2026	K Sq. Ft	☐	1932
Other Area	653	K Sq. Ft	☐	
City	Newport News	(none)	☑	
State	VA	(none)	☑	
Degrees Latitude	37	Degrees	☑	
Minutes Latitude	8	Min	☑	
Degrees Longitude	76	Degrees	☑	
Minutes Longitude	37	Min	☑	
Elevation	12	Ft	☑	
Heating Degree Days	3752	F	☐	3495
Cooling Degree Days	1585	F	☐	1549
Winter Design Temperature	20	F	☑	
Summer Design Temperature	90	F	☑	
Mean Coincident Wet Bulb (MCWB) Temperature	76	F	☑	
Mean Daily Temperature Range	17	F	☑	
Total Global Radiation	1325.2	K J/Sq. M	☑	
Radiation / Degree Days	27.6	Btu/SF/DD	☑	

Description	Value	Units	No Revision	Revised Value
Summer A/C Criteria Dry Bulb Hours > 80 °F	809	Hrs	☑	
Summer A/C Criteria Wet Bulb Hours > 67 °F	2290	Hrs	☑	
Air Conditioning Logic Test	1	(none)	☑	
Annual Dry Bulb Hours	4483	Hrs	☑	
Annual Dry Bulb Hours (80 - 84 °F)	511	Hrs	☑	
Annual Dry Bulb Hours (85 - 89 °F)	243	Hrs	☑	
Mean Coincident Wet Bulb Temperature (80 - 84 °F)	73	F	☑	
Mean Coincident Wet Bulb Temperature (85 - 89 °F)	75	F	☑	
Cooling Factor	5.47	(none)	☑	
Heating Factor	1.17	(none)	☑	
Lighting Cooling Fraction	0.46	%	☑	
Lighting Heating Fraction	0.16	%	☑	
Steam and Hot Water Distribution Systems	75	K Lin Ft	☐	
Ground Temperature	57.74	F	☑	
Full Load Heating Hours	1876	Hrs	☑	
Full Load Cooling Hours	3170	Hrs	☑	
Full Load Heating Hours for Family Housing	1801	Hrs	☑	
Heating Season Days	175.8	Days	☑	
Cooling Season Days	72	Days	☑	
Location Indices	1	(none)	☑	
Baseload Demand Cost	64.8	$/kW	☐	11.354
Summer Demand Cost	64.8	$/kW	☐	12.616
Gas Cost	3.35988	$/MBtu	☐	3.59
Oil Cost	4.98	$/MBtu	☐	4.54
Coal Cost	2.22	$/MBtu	☑	
Electricity Cost	0.024	$/kWh	☐	0.01968
Peak Demand for Electricity	21850	kW	☐	
Discount Factor Table	3	(none)	☐	
Electricity Generated by Coal	0.46	%	☐	
Electricity Generated by Petroleum	0.03	%	☐	
Electricity Generated by Gas	0.02	%	☐	
Electricity Generated by Hydro-electric Power	0.01	%	☐	
Electricity Generated by Nuclear Power	0.48	%	☐	
Electricity Generated by Other Means	0	%	☐	
Carbon Dioxide Emissions	348.77	Lb/MBtu	☐	
Sulfur Dioxide Emissions	5.3	Lb/MBtu	☐	
Nitrogen Oxide Emissions	1.18	Lb/MBtu	☐	
Carbon Monoxide Emissions	0.05	Lb/MBtu	☐	
Hydrocarbon Emissions	0.01	Lb/MBtu	☐	
Particulate Emissions	0.17	Lb/MBtu	☐	
Purchased Electricity	125118	MWH	☐	
Exterior Lighting	4819	Lights	☐	
Wind Power Class	2	(none)	☐	

Fort Hood, TX

This visit was conducted on 22 October 1996. IGT personnel met with Messrs. Bobby Lynn, Albert McNamee, and Robert Kennedy. The following bullets highlight the information obtained through this visit:

- They are looking for a peak power generator.

- They use the NIST report on "Present worth factors," which seems to penalize natural gas in Texas, Region 3.

- Each Division Contractor is gathering nameplate data on all energy using equipment to obtain a Title 5 environment permit. This will cover boilers, water heaters, radiant heaters, and any other emission source.

- This DoD installation, together with five other U.S. Air Force facilities, went to the Defense Fuel Supply Center and negotiated a transportation agreement with the local distribution company. Commodity charge of $2.74/Mcf, which includes a transportation charge of $0.98/Mcf.

- Electricity cost is about $0.055/kWh.

- Five hundred and fifteen gas and electric meters are read every month. They have very few water meters.

- They collect electricity consumption data every 15 minutes for the whole substation. They have two substations – one with 16 circuits and the other with seven circuits. Hourly data is collected by each circuit.

- Gas consumption data is collected every hour for the main post and for West Fort Hood.

- Electric demand charge has gone up from $73.55/kW/Month to $142.99/kW/Month in just six years.

- Interested in an R&D field test/demonstration of an advanced gas-fired technology.

- Suggestion to add gas dryers for family housing as a new ECO.

Table D2 below shows the updated data sheet of REEP data elements for Fort Hood, TX.

Table D2. REEP data elements for Fort Hood, TX.

Description	Value	Units	No Revision	Revised Value
Department of Defense Service	ARMY	(none)	☑	
Installation	FT HOOD	(none)	☑	
Major Command	FORSCOM	(none)	☑	
Population	65128	Persons	☐	61103
Water Service Quantity	2098983	Kgal	☐	2478457
Water Service Total Cost	732112	$	☐	766019
Water Service Unit Cost	0.35	$/Kgal	☐	0.31
Water Distribution	2117	K Lin Ft	☐	2073
Sewage Service Quantity	1380635	Kgal	☐	1369887
Sewage Service Total Cost	527922	$	☐	630345
Sewage Service Unit Cost	0.38	$/Kgal	☐	0.46
Electricity Service Quantity	371611	MWH	☐	384743
Electric Service Total Cost	20201840	$	☐	20307847
Electric Service Unit Cost	54.36	$/MWH	☐	52.11
Gas, Oil, and Coal Service Total Cost	5344191	$	☐	4239121
Building Service Quantity	25517	K Sq. Ft	☐	26829
Baseline (1985) Building Area	23449	KSF	☐	
Baseline (1985) Energy consumption	2619417	MBtu	☐	
Gas Fired Heating Plant > 3.5 MBtu/Hr capacity	884	MBtu/Hr	☐	
Gas Fired Heating Plant > 3.5 MBtu/Hr Consumed	218205	MBtu	☐	
Oil Fired Heating Plant > 3.5 MBtu/Hr capacity	0	MBtu/Hr	☐	
Oil Fired Heating Plant > 3.5 MBtu/Hr Consumed	0	MBtu	☐	
Coal Fired Heating Plant > 3.5 MBtu/Hr capacity	0	MBtu/Hr	☐	
Coal Fired Heating Plant > 3.5 MBtu/Hr Consumed	0	MBtu	☐	
Gas Fired Heating Plant .75 - 3.5 MBtu/Hr capacity	1645	MBtu/Hr	☐	
Gas Fired Heating Plant .75 - 3.5 MBtu/Hr Consumed	382669	MBtu	☐	
Oil Fired Heating Plant .75 - 3.5 MBtu/Hr capacity	0	MBtu/Hr	☐	
Oil Fired Heating Plant .75 - 3.5 MBtu/Hr Consumed	0	MBtu	☐	
Coal Fired Heating Plant .75 - 3.5 MBtu/Hr capacity	0	MBtu/Hr	☐	
Coal Fired Heating Plant .75 - 3.5 MBtu/Hr Consumed	0	MBtu	☐	
Gas Fired Heating Plant < .75 MBtu/Hr capacity	1577	MBtu/Hr	☐	
Gas Fired Heating Plant < .75 MBtu/Hr	359905	MBtu	☐	

Description	Value	Units	No Revision	Revised Value
Consumed				
Oil Fired Heating Plant < .75 MBtu/Hr capacity	0	MBtu/Hr	☐	
Oil Fired Heating Plant < .75 MBtu/Hr Consumed	361	MBtu	☐	
Coal Fired Heating Plant < .75 MBtu/Hr capacity	0	MBtu/Hr	☐	
Coal Fired Heating Plant < .75 MBtu/Hr Consumed	0	MBtu	☐	
A/C and Chilled Water Plant > 100 Tons capacity	13412	Tons	☐	
A/C and Chilled Water Plant 5 - 100 Ton capacity	11954	Tons	☐	
A/C and Chilled Water Plant < 5 Tons capacity	13941	Tons	☐	
Training Area	688	K Sq. Ft	☐	
Maintenance and Production Area	3347	K Sq. Ft	☐	3487
Research, Development, and Testing Area	8	K Sq. Ft	☐	
Storage Area	1470	K Sq. Ft	☐	
Hospital and Medical Area	707	K Sq. Ft	☐	
Administrative Area	1211	K Sq. Ft	☐	
Barracks Area	6042	K Sq. Ft	☐	
Common Facilities Area	1852	K Sq. Ft	☐	
Family Housing Area	8409	K Sq. Ft	☐	8729
Other Area	1783	K Sq. Ft	☐	
City	Killeen	(none)	☑	
State	TX	(none)	☑	
Degrees Latitude	31	Degrees	☑	
Minutes Latitude	4	Min	☑	
Degrees Longitude	43	Degrees	☑	
Minutes Longitude	50	Min	☑	
Elevation	923	Ft	☑	
Heating Degree Days	1959	F	☐	
Cooling Degree Days	2792	F	☐	
Winter Design Temperature	25	F	☐	
Summer Design Temperature	97	F	☐	
Mean Coincident Wet Bulb (MCWB) Temperature	73	F	☐	
Mean Daily Temperature Range	23	F	☐	
Total Global Radiation	1467.1	K J/Sq. M	☐	
Radiation / Degree Days	49.22	Btu/SF/DD	☐	
Summer A/C Criteria Dry Bulb Hours > 80 °F	1791	Hrs	☐	
Summer A/C Criteria Wet Bulb Hours > 67 °F	3043	Hrs	☐	
Air Conditioning Logic Test	1	(none)	☐	
Annual Dry Bulb Hours	5892	Hrs	☐	
Annual Dry Bulb Hours (80 - 84 °F)	782	Hrs	☐	
Annual Dry Bulb Hours (85 - 89 °F)	556	Hrs	☐	

Description	Value	Units	No Revision	Revised Value
Mean Coincident Wet Bulb Temperature (80 - 84 °F)	70	F	☐	
Mean Coincident Wet Bulb Temperature (85 - 89 °F)	72	F	☐	
Cooling Factor	6.46	(none)	☐	
Heating Factor	0.61	(none)	☐	
Lighting Cooling Fraction	0.71	%	☐	
Lighting Heating Fraction	0.03	%	☐	
Steam and Hot Water Distribution Systems	21	K Lin Ft	☐	
Ground Temperature	63.12	F	☐	
Full Load Heating Hours	1093	Hrs	☐	
Full Load Cooling Hours	3527	Hrs	☐	
Full Load Heating Hours for Family Housing	1045	Hrs	☐	
Heating Season Days	136	Days	☐	
Cooling Season Days	130.3	Days	☐	
Location Indices	0.89	(none)	☐	
Baseload Demand Cost	150.722	$/kW	☐	142.99
Summer Demand Cost	150.722	$/kW	☐	142.99
Gas Cost	4.3963!	$/MBtu	☐	2.3584
Oil Cost	4.98	$/MBtu	☐	
Coal Cost	2.22	$/MBtu	☐	
Electricity Cost	0.0248	$/kWh	☐	
Peak Demand for Electricity	68760	kW	☐	81546
Discount Factor Table	3	(none)	☐	
Electricity Generated by Coal	0.49	%	☐	
Electricity Generated by Petroleum	0	%	☐	
Electricity Generated by Gas	0.39	%	☐	
Electricity Generated by Hydro-electric Power	0.01	%	☐	
Electricity Generated by Nuclear Power	0.11	%	☐	
Electricity Generated by Other Means	0	%	☐	
Carbon Dioxide Emissions	501.23	Lb/MBtu	☐	
Sulfur Dioxide Emissions	1.42	Lb/MBtu	☐	
Nitrogen Oxide Emissions	1.48	Lb/MBtu	☐	
Carbon Monoxide Emissions	0.1	Lb/MBtu	☐	
Hydrocarbon Emissions	0.01	Lb/MBtu	☐	
Particulate Emissions	0.18	Lb/MBtu	☐	
Purchased Electricity	371611	MWH	☐	389743
Exterior Lighting	11736	Lights	☐	
Wind Power Class	2	(none)	☐	

Fort Riley, KS

This visit was conducted on 20 September 1996. IGT personnel met with Mr. Mark Imel and his staff in the Engineering Plans and Services. The following bullets highlight the information obtained through this visit:

- Generally, they have trouble gathering data since most of the available information is either inadequate or incomplete.
- Would like to see some efforts made to regularly update data from installations.
- Interested in composite radiant tube technology. At present, they use a 12-hour setback in bay areas.
- Also interested in desiccant cooling technologies.
- Two TECOCHILL 340 RT gas engine-driven chillers are installed at a hospital site. They also have a heat recovery with these units, which is not addressed in the current version of the REEP program.
- Electric demand is 7 of 12 months based on an 80 percent ratchet.
- Looked at gas-fired heat pump algorithm in REEP; does not seem to account for supplemental heat and seems to consider the replacement of electric heat pump only. Also, there is no demand charge adjustment for a drop in electric demand (if applicable).
- Currently evaluating a 5 MW cogeneration plant, which is expected to cost about $350/kW installed. They do not have a use for the waste heat.
- This DOD installation already has old direct-fired natural gas chillers. Cannot use REEP to evaluate alternative gas chillers since the current REEP chiller ECOs compare new chillers to electric chillers.
- The hospital is looking into various incinerator/disinfection technologies. Also looked into municipal solid waste plants, but could not meet emission restrictions.
- They suggested that some parametric capability be built into the next version of the REEP program to enable “what if” analyses in a spreadsheet mode.

- They expect significant changes in natural gas prices (to them) in the next few years.

Table D3 below shows the updated data sheet of REEP data elements for Fort Riley, KS.

Table D3. REEP data elements for Fort Riley, KS.

Description	Value	Units	No Revision	Revised Value
Department of Defense Service	ARMY	(none)	☑	
Installation	FT RILEY	(none)	☑	
Major Command	FORSCOM	(none)	☑	
Population	35102	Persons	☐	
Water Service Quantity	1380726	Kgal	☐	
Water Service Total Cost	947991	$	☐	
Water Service Unit Cost	0.69	$/Kgal	☐	
Water Distribution	2360	K Lin Ft	☐	
Sewage Service Quantity	683469	Kgal	☐	
Sewage Service Total Cost	515684	$	☐	
Sewage Service Unit Cost	0.75	$/Kgal	☐	
Electricity Service Quantity	230164	MWH	☐	
Electric Service Total Cost	9416910	$	☐	
Electric Service Unit Cost	40.91	$/MWH	☐	
Gas, Oil, and Coal Service Total Cost	6464772	$	☐	
Building Service Quantity	12585	K Sq. Ft	☐	
Baseline (1985) Building Area	14766	KSF	☐	
Baseline (1985) Energy consumption	1890767	MBtu	☐	
Gas Fired Heating Plant > 3.5 MBtu/Hr capacity	400	MBtu/Hr	☐	
Gas Fired Heating Plant > 3.5 MBtu/Hr Consumed	276400	MBtu	☐	
Oil Fired Heating Plant > 3.5 MBtu/Hr capacity	0	MBtu/Hr	☐	
Oil Fired Heating Plant > 3.5 MBtu/Hr Consumed	0	MBtu	☐	
Coal Fired Heating Plant > 3.5 MBtu/Hr capacity	0	MBtu/Hr	☐	
Coal Fired Heating Plant > 3.5 MBtu/Hr Consumed	0	MBtu	☐	
Gas Fired Heating Plant .75 - 3.5 MBtu/Hr capacity	400	MBtu/Hr	☐	
Gas Fired Heating Plant .75 - 3.5 MBtu/Hr Consumed	489800	MBtu	☐	
Oil Fired Heating Plant .75 - 3.5 MBtu/Hr capacity	0	MBtu/Hr	☐	
Oil Fired Heating Plant .75 - 3.5 MBtu/Hr Consumed	0	MBtu	☐	
Coal Fired Heating Plant .75 - 3.5 MBtu/Hr capacity	0	MBtu/Hr	☐	
Coal Fired Heating Plant .75 - 3.5 MBtu/Hr Consumed	0	MBtu	☐	

Description	Value	Units	No Revision	Revised Value
Gas Fired Heating Plant < .75 MBtu/Hr capacity	400	MBtu/Hr	☐	
Gas Fired Heating Plant < .75 MBtu/Hr Consumed	138700	MBtu	☐	
Oil Fired Heating Plant < .75 MBtu/Hr capacity	0	MBtu/Hr	☐	
Oil Fired Heating Plant < .75 MBtu/Hr Consumed	393400	MBtu	☐	
Coal Fired Heating Plant < .75 MBtu/Hr capacity	0	MBtu/Hr	☐	
Coal Fired Heating Plant < .75 MBtu/Hr Consumed	0	MBtu	☐	
A/C and Chilled Water Plant ≥ 100 Tons capacity	3137	Tons	☐	
A/C and Chilled Water Plant 5 - 100 Ton capacity	0	Tons	☐	
A/C and Chilled Water Plant < 5 Tons capacity	217	Tons	☐	
Training Area	653	K Sq. Ft	☐	407
Maintenance and Production Area	201	K Sq. Ft	☐	155
Research, Development, and Testing Area	0	K Sq. Ft	☐	
Storage Area	306	K Sq. Ft	☐	742
Hospital and Medical Area	469	K Sq. Ft	☐	506
Administrative Area	612	K Sq. Ft	☐	598
Barracks Area	2686	K Sq. Ft	☐	2659
Common Facilities Area	1490	K Sq. Ft	☐	1112
Family Housing Area	5426	K Sq. Ft	☐	5524
Other Area	742	K Sq. Ft	☐	1144
City	Manhattan	(none)	☑	
State	KS	(none)	☑	
Degrees Latitude	39	Degrees	☑	
Minutes Latitude	3	Min	☑	
Degrees Longitude	96	Degrees	☑	
Minutes Longitude	46	Min	☑	
Elevation	1065	Ft	☑	
Heating Degree Days	5306	F	☑	
Cooling Degree Days	1503	F	☑	
Winter Design Temperature	3	F	☑	
Summer Design Temperature	95	F	☑	
Mean Coincident Wet Bulb (MCWB) Temperature	75	F	☑	
Mean Daily Temperature Range	22	F	☑	
Total Global Radiation	1384.8	K J/Sq. M	☑	
Radiation / Degree Days	21.86	Btu/SF/DD	☑	
Summer A/C Criteria Dry Bulb Hours > 80 °F	1094	Hrs	☑	
Summer A/C Criteria Wet Bulb Hours > 67 °F	1641	Hrs	☑	
Air Conditioning Logic Test	1	(none)	☑	
Annual Dry Bulb Hours	3924	Hrs	☑	
Annual Dry Bulb Hours (80 - 84 °F)	520	Hrs	☑	
Annual Dry Bulb Hours (85 - 89 °F)	327	Hrs	☑	
Mean Coincident Wet Bulb Temperature (80 - 84 °F)	69	F	☑	

Description	Value	Units	No Revision	Revised Value
Mean Coincident Wet Bulb Temperature (85 - 89 °F)	72	F	☑	
Cooling Factor	5.38	(none)	☑	
Heating Factor	1.65	(none)	☑	
Lighting Cooling Fraction	0.44	%	☑	
Lighting Heating Fraction	0.22	%	☑	
Steam and Hot Water Distribution Systems	22	K Lin Ft	☑	
Ground Temperature	53.08	F	☑	
Full Load Heating Hours	1959	Hrs	☑	
Full Load Cooling Hours	2122	Hrs	☑	
Full Load Heating Hours for Family Housing	1901	Hrs	☑	
Heating Season Days	210.3	Days	☑	
Cooling Season Days	68	Days	☑	
Location Indices	0.96	(none)	☐	
Baseload Demand Cost	42.12	$/kW	☐	
Summer Demand Cost	42.12	$/kW	☐	
Gas Cost	3.42	$/MBtu	☐	
Oil Cost	4.98	$/MBtu	☐	
Coal Cost	2.22	$/MBtu	☐	
Electricity Cost	0.030	$/kWh	☐	
Peak Demand for Electricity	37836	kW	☐	
Discount Factor Table	2	(none)	☐	
Electricity Generated by Coal	0.7	%	☐	
Electricity Generated by Petroleum	0	%	☐	
Electricity Generated by Gas	0.04	%	☐	
Electricity Generated by Hydro-electric Power	0	%	☐	
Electricity Generated by Nuclear Power	0.26	%	☐	
Electricity Generated by Other Means	0	%	☐	
Carbon Dioxide Emissions	507.37	Lb/MBtu	☐	
Sulfur Dioxide Emissions	5.49	Lb/MBtu	☐	
Nitrogen Oxide Emissions	1.75	Lb/MBtu	☐	
Carbon Monoxide Emissions	0.08	Lb/MBtu	☐	
Hydrocarbon Emissions	0.01	Lb/MBtu	☐	
Particulate Emissions	0.25	Lb/MBtu	☐	
Purchased Electricity	230164	MWH	☐	
Exterior Lighting	3104	Lights	☐	
Wind Power Class	4	(none)	☐	

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